United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-179**

An Analysis of the Minerals Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
General Technical Report RM-179

September 1989

An Analysis of the Minerals Situation in the United States: 1989–2040

ACKNOWLEDGMENTS

Though prepared by the Resources Program and Assessment Staff, a number of people contributed to this Analysis of the Minerals Situation in the United States: 1989–2040. William E. Shands and Lisa Fernandez of The Conservation Foundation served as contributing editors to the volume. Buster LaMoure, Director, and Floyd Deloney and Tom King, of the Forest Service Minerals and Geology Management Staff provided information on Forest Service minerals activity. Thanks are due to many specialists in the Department of Interior's Bureau of Mines and personnel at the Department of Energy for providing information on minerals supply and demand.

Contents

	Page
INTRODUCTION	1
Differences from Other Forest and Range Resources	1
Economic Contributions	1
Strategic Importance	2
Laws that Affect Minerals Resources	3
Federal Agencies Responsible for Minerals Management	4
Minerals and Indicator Minerals	4
TRENDS IN CONSUMPTION OF MINERALS AND PROJECTED DEMAND	4
Past and Current Consumption Trends	8
Energy Minerals	8
Metallic Minerals	9
Industrial Minerals	10
Projected Trends in U.S. Demand	11
Energy Minerals	11
Metallic Minerals	11
Industrial Minerals	13
Trends in Mineral Imports	13
Energy Minerals	14
Metallic Minerals	14
Industrial Minerals	15
THE NATION'S MINERALS RESOURCES	15
Location	15
Ownership	16
Energy Minerals	16
Metallic Minerals	19
Industrial Minerals	19
THE MINERALS SUPPLY SITUATION	19
How Prices Affect Minerals Supplies	20
Energy Minerals	20
Metallic Minerals	21
Industrial Minerals	21
Recycling: Another Source of Supply	22
The Nation's Strategic Stockpiles	22
Security of Foreign Supplies	22
HOW SUPPLY COMPARES TO EXPECTED DEMANDS	23
Minerals Demand: Summary and Analysis	23
Energy Minerals	23
Metallic Minerals	24
Industrial Minerals	24
The Minerals Supply Situation: Summary and Analysis	24
Energy Minerals	24
Metallic Minerals	24
Industrial Minerals	24
Price/cost and Supply Interactions	24
The Future	24
SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF THE SUPPLY/DEMAND COMPARISONS	25
National Effects	25
Effects on Regions and Communities	25
Economic Impacts	26
Social Impacts	26
Environmental Impacts	27

Page

OPPORTUNITIES FOR MEETING THE NATION'S MINERALS NEEDS ... 28
Increasing Domestic Supplies ... 29
Improving Business Climate ... 29
Increasing Mineral Production on Private Land ... 29
Increasing Mineral Production on Federal Land ... 29
Improving Information on Domestic Minerals Resources ... 29
Increasing Research and Development of Technology. ... 29
Ensuring Emergency Supplies of Critical Minerals. ... 30
Increasing Imports ... 30
Extending Supplies ... 30
Substituting Nonmineral Materials ... 30
CONSTRAINTS TO IDENTIFIED OPPORTUNITIES ... 30
Investment Uncertainty and Risk ... 31
Comparative Costs ... 31
Inadequate Information ... 31
Development Opposition ... 31
Inadequte Management of Minerals on Federal Lands ... 31
National Minerals Policy ... 31
Constraints to Increasing Imports ... 32
Constraints to Efficiencies in Mining, Use, and Recycling ... 32
Constraints to Use of Substitutes ... 32
IMPLICATIONS FOR RENEWABLE RESOURCE PROGRAMS ... 32
Improved Minerals Management Capability ... 34
Integrating Minerals into Land and Resources Planning ... 34
Improvements in the Legal and Administrative Framework ... 34
Research Needs ... 34
Alternative Futures ... 34
Policy Questions for Forest Service Programs ... 35
REFERENCES ... 36

An Analysis of the Minerals Situation in the United States: 1989–2040

INTRODUCTION

Highlights

- Minerals are essential to modern life.
- Minerals are important to the national economy and the economies of many states.
- Some minerals are of strategic importance, and essential to national economic and military security.
- Minerals are different from other forest and rangeland resources because they are more difficult to find, inventory and develop.
- Mineral development is governed by a complex set of laws, and administered by a number of federal agencies.

Minerals are important forest and rangeland resources There are approximately 2,400 minerals, of which 100 are of worldwide economic importance. Minerals are naturally occurring inorganic substances composed of one or more elements. However, for this report, minerals are considered a whole array of geologically derived resources that includes coal and oil used for energy; metallic minerals that contain lead, copper, cobalt, gold, and silver; gems; and the common building materials like sand, gravel, and clay. To simplify the discussion, this report frequently will use the term "mineral" when referring to constituent elements of minerals. Thus iron, when referred to as a mineral, is actually an element found in many minerals such as hematite, bornite, etc.

Differences from Other Forest and Range Resources

A number of factors distinguish minerals from other forest and range resources.

- Unlike other resources found on forest and rangelands, most minerals are nonrenewable, finite, and the result of millions of years of geologic, biologic, and chemical processes.
- Minerals are far more difficult to inventory, explore, and develop than other forest and rangeland resources.
- Minerals are traded in global markets to a greater degree than other forest and rangeland commodities, and governments intervene in the supply and prices of virtually all critical minerals.
- A number of minerals are strategically important to the United States and its allies because of their role in our economy, energy, and the manufacture of weapons systems.
- While the United States has abundant supplies of many minerals, it must depend on foreign countries for some minerals that have critical economic and strategic importance.

Economic Contributions

Minerals are major components of our national, state, and local economies. Nationally, the minerals industry contributed $122.8 billion to the gross national product (GNP) in 1985. Oil and gas extraction accounted for $96.4 billion, coal for $16.9 billion, and metallic minerals and mineral materials for $9.4 billion. Altogether, the minerals industry contributed 3.1% to the total 1985 GNP (U.S. Department of Commerce, Bureau of the Census [USDC BC] 1986). Although the industry's contribution to total GNP may seem small, they supply a large portion of the raw materials on which our economy depends. The U.S. imports far more minerals than it exports, but minerals still are a significant item in foreign trade. In 1985, nonfuel minerals sales overseas totaled $13 billion, about 6% of the dollar value of all exports (U.S. Department of Interior, Bureau of Mines [USDI BM] 1987a; U.S. Department of Commerce, Bureau of Census [USDC BC] 1986). Some 83.3 million short tons of coal worth $2.7 billion were exported in 1986 (U.S. Department of Energy [US DOE] 1987b).

Value added (calculated as receipts plus capital expenditures, minus production and shipping costs) by the mining industry in 1982 totaled $188 billion, accounting for 40% of value added by all raw material industries, which includes agriculture, forestry, and fishing (USDC BC 1984). In 1982, the last year figures from the Bureau of Census are available, 73,000 nationwide establishments employed more than 1.1 million persons in mineral exploration, extraction, and milling, with a payroll of $28.6 billion (USDC BC 1986).

Oil and gas is the largest segment of the industry and employes 600,000 workers, or about 60% of the minerals workforce in 1982. Coal mining follows, with 250,000 workers (23%), mineral materials with 110,000 workers (10%), and metallic minerals industries with 68,000 workers (8%). The minerals industry is made up largely of small companies with less than 20 workers. In 1982, just 14% of the 73,000 minerals establishments counted by the Bureau of the Census had more than 20 employees (USDC BC 1984); however, this 14% accounts for a much larger proportion of minerals production in the United States.

Minerals production and processing are major components of the economies of many states. The importance of minerals to the economies of individual states is indicated by minerals production per capita (table 1). Some states are significant minerals producers. Texas, Louisiana, Oklahoma, California, New Mexico, Wyoming, and West Virginia contributed more than 75% of the $188 billion in value added by minerals production and processing in 1982.

Arizona's copper and Minnesota's iron ores contributed about 33% of the value added by metallic minerals industries. Minerals produced in Colorado, Nevada, New

Table 1. Value of nonfuel and fossil fuel mineral production per capita by state,1985.

State	Population (thousands)	Value of mineral production $ (thousands)	per capita Dollars	per capita Rank	Value of fossil fuel production $ (thousands)	per capita Dollars	per capita Rank
Alabama	4,021	405,915	101	20	1,618,678	403	16
Alaska	521	89,969	173	10	16,322,019	31,328	1
Arizona	3,187	1,550,085	486	3	246,766	77	26
Arkansas	2,359	256,697	109	18	854,107	362	17
California	26,365	2,094,796	79	24	11,866,004	450	15
Connecticut	3,174	72,386	23	47			
Colorado	3,231	408,178	126	16	1,679,821	520	13
Delaware	622	4,029	6	50			
Florida	11,366	1,559,266	137	14	301,681	27	29
Georgia	5,976	946,075	158	11			
Hawaii	1,054	53,272	51	37			
Idaho	1,005	348,154	346	6			
Illinois	11,535	459,920	40	39	2,224,616	193	19
Indiana	5,499	302,954	55	35	964,980	175	21
Iowa	2,884	228,017	79	25	14,893	5	33
Kansas	2,450	322,170	131	15	2,493,154	1,018	11
Kentucky	3,726	267,558	72	27	4,199,363	1,127	10
Louisiana	4,481	522,268	117	17	26,603,982	5,937	3
Maine	1,164	41,108	35	42			
Maryland	4,392	258,274	59	32	75,245	17	31
Massachusetts	5,822	117,205	20	48			
Michigan	9,088	1,347,853	148	12	1,132,335	125	23
Minnesota	4,193	1,547,958	369	5			
Mississippi	2,613	102,793	39	40	1,334,864	511	14
Missouri	5,029	734,960	146	13	5,868	1	35
Montana	828	200,272	242	8	1,681,480	2,036	8
Nebraska	1,606	99,970	62	31	173,110	108	24
Nevada	936	630,883	674	2	73,210	78	25
New Hampshire	998	32,900	33	44			
New Jersey	7,562	177,576	23	46			
New Mexico	1,450	656,889	453	4	4,821,283	3,325	4
New York	17,783	657,308	37	41	132,161	7	32
North Carolina	6,255	432,756	69	28			
North Dakota	685	24,184	35	43	2,040,042	2,978	5
Ohio	10,744	607,127	57	33	1,818,673	169	22
Oklahoma	3,301	251,607	76	26	8,793,517	2,664	6
Oregon	2,687	130,296	48	38	9,800	4	34
Pennsylvania	11,853	804,474	68	29	2,390,547	202	18
Rhode Island	968	12,192	13	49			
South Carolina	3,347	275,929	82	23			
South Dakota	708	207,339	293	7	44,878	63	27
Tennessee	4,762	472,287	99	21	218,195	46	28
Texas	16,370	1,733,359	106	19	36,654,454	2,239	7
Utah	1,645	312,359	190	9	1,597,920	971	12
Vermont	535	49,854	93	22			
Virginia	5,706	381,276	67	30	1,077,737	189	20
Washington	4,409	243,670	55	34	111,838	25	30
West Virginia	1,936	105,409	54	36	3,863,093	1,995	9
Wisconsin	4,775	125,110	26	45			
Wyoming	509	552,463	1,085	1	7,893,991	15,509	2
TOTAL	238,115	22,813,434	$96		145,334,305	610	

Sources: US DOE 1987a–d, USDI BM 1987a.

Mexico, Wyoming, Missouri, and Idaho contributed, (in that order) to another 33% of value added by metallic minerals industries. West Virginia and Kentucky contributed about 40% of the total $18 billion value added by coal mining in 1982, with Pennsylvania, Illinois, Wyoming, Virginia, and Ohio accounting for another 40%.

The domestic minerals industry has been in an economic decline since 1981 when combined production of all minerals peaked. However, the situation varies among sectors of the minerals industry. Bituminous coal production has increased significantly since 1973, while anthracite (hard coal) production has fallen over the past decade. Production of key metallic minerals that include those yielding iron, copper, lead, and zinc has fallen over the past 10 years. This reflects a decline in primary metals manufacturing (USDC BC 1986).

Strategic Importance

Energy minerals and some metallic minerals are of strategic importance to the Nation's security. U.S. military forces could not operate without fuel—a fact recognized by President Taft in 1909, when he set aside oil reserves in California and Wyoming to assure fuel for the Navy (Wilkinson and Anderson 1987). Minerals also are key components of modern weapons systems. Tough, heat-resistant, and lightweight alloys are used in the engines of supersonic jet aircraft; chrome is used to line the barrels of cannon to withstand the force and heat of a high velocity projectile.

Laws That Affect Minerals Resources

The body of law that affects the development of federally-owned minerals is extensive and complex. The most important are the Mining Law of 1872, the Mineral Leasing Act of 1920, the Mineral Materials Act of 1947, the Mineral Leasing Act for Acquired Lands of 1947, the Surface Resources Act of 1955, and the Surface Multiple-Use Mining Act of 1955. These laws determine whether a mineral is "locatable," "leasable," or "mineral materials subject to sale." They control the exploration, development, and removal of minerals owned by the federal government.

General Mining Law of May 10, 1872.—This Act establishes the principles of discovery, the right of possession, assessment work, and patent provisions that cover hardrock minerals on lands reserved from the public domain for national forest purposes The laws applies to lode, placer, and millsite claims and tunnel sites. Except as otherwise provided, all valuable mineral deposits, and the lands where they are found, are free and open to exploration, occupation, and purchase under regulations prescribed by law.

Mineral Resources on Weeks Law Lands Act of March 4, 1917.—This Act authorizes the Secretary of Agriculture (now Secretary of the Interior) to issue permits and leases for prospecting, development, and utilization of hardrock minerals on lands acquired under the authority of the Weeks Law.

Mineral Lands Leasing Act of February 25, 1920.—This Act authorizes the Secretary of the Interior to issue leases for the disposal of certain minerals (currently applies to coal, phosphate, sodium, potassium, oil, oil shale, gilsonite, and gas). The Act applies to national forest lands reserved from the public domain, including lands received in exchange for timber or other public domain lands and lands with minerals reserved under special authority.

Materials Act of July 21, 1947.—This Act provides for the disposal of mineral materials on the public lands through bidding, negotiated contracts, or free use.

Mineral Leasing Act for Acquired Lands of August 7, 1947.—This Act extends the provisions of the mineral leasing laws to federally-owned mineral deposits on acquired National Forest System lands and requires the consent of the Secretary of Agriculture prior to leasing.

Multiple-Use Mining Act of July 23, 1955.—This Act requires the disposal of common varieties of sand, stone, gravel, pumice, pumicite, and cinders under the provisions of the Materials Act of July 31, 1947, and gives the Secretary of Agriculture disposal authority. It also provides that rights under any mining claim located under the mining laws are subject to the right of the United States to management and dispose of surface resources.

Geothermal Steam Act of December 24, 1970.—This Act provides for the leasing of National Forest System lands for geothermal steam development by the Secretary of the Interior, subject to the consent of, and conditions prescribed by, the Secretary of Agriculture.

Mining and Mineral Policy Act of December 31, 1970.—This Act states the continuing policy of the federal government is to foster and encourage private enterprise in the development of economically sound and stable domestic mining and minerals industries and the orderly and economic development of domestic mineral resources.

Federal Coal Leasing Amendments Act of August 4, 1976.—This Act, amending the Mineral Lands Leasing Act, specifies that coal leases on National Forest System lands may be issued only upon consent of, and to conditions prescribed by, the Secretary of Agriculture. It also provides that no leases will be issued unless the lands have been included in a comprehensive land use plan and the sale is compatible with the plan. The Act authorizes the issuance of the license to conduct exploration for coal.

Federal Land Policy and Management Act of October 21, 1976.—This Act defines procedures for the withdrawal of lands from mineral entry. It reserves the rights to prospect for, mine, and remove the minerals in lands conveyed to others to the United States. It also requires the recording of claims with the Bureau of Land Management.

Surface Mining Control and Reclamation Act of August 3, 1977.—This Act provides for cooperation between the Secretary of the Interior and the states in the regulation of surface coal mining. It also restricts or prohibits surface coal mining operations on National Forest System lands, subject to valid existing rights and compatibility determinations.

Energy Security Act of June 30, 1980.—This Act directs the Secretary of Agriculture to process applications for leases and permits to explore, drill, and develop resources on National Forest System lands, notwithstanding the current status of the land and resource management plan.

National Materials and Minerals Policy, Research and Development Act of October 2, 1980.—This Act restates congressional policy to promote an adequate and stable supply of materials with appropriate attentions to a long-term balance between resource production, healthy environment, and natural resource conservation. It also requires the Secretary of the Interior to improve the availability and analysis of mineral data in federal land use decision-making.

The Federal Onshore Oil and Gas Leasing Reform Act of December 22, 1987.—This Act significantly changed the Forest Service's role in leasing and operations. The act gave the Forest Service the authority to analyze and approve any surface-disturbing activity on a federal oil

and gas lease. The Secretary of Interior cannot issue a lease on any National Forest System land over the objection of the Secretary of Agriculture.

Federal Agencies Responsible for Minerals Management

Several federal agencies play major roles in establishing policies and administering programs that affect minerals directly or indirectly. Within the Department of the Interior, responsibility to manage federally-owned minerals, data collection, planning, research, collecting fees, and managing minerals on federal lands is dispersed among five agencies.

The Bureau of Land Management (BLM) manages fossil fuel and metallic minerals for the public domain it administers. BLM also is responsible for minerals retained in federal ownership when surface ownership has been transferred to private parties.

The Geological Survey (USGS) collects information on the Nation's mineral resources. It inventories mineral deposits and their potential.

The Bureau of Mines (BM) collects and analyzes scientific and technical information about the Nation's minerals including supplies, consumption, and the minerals situation worldwide. It also conducts mining research and produces authoritative information on the nation's nonenergy minerals in its annual *Minerals Yearbooks* and other publications.

The Office of Surface Mining, Reclamation and Enforcement (OSMRE) administers the Surface Mining Control and Reclamation Act of 1977 that covers surface mining for coal on both private and public land. Through provisions of the act, OSMRE oversees surface mine regulation by the states and administers a federal fund for reclamation of abandoned mines.

The Minerals Management Service collects revenues from leasing federal minerals both onshore and on the outer continental shelf, and has primary responsibility for development of federal offshore mineral resources.

The Forest Service is responsible for integrating use of minerals with the use of surface resources. To do this, it develops plans for surface and mineral uses, reviews and approves proposals for mineral activities, monitors mineral operator protection of surface resources, and oversees reclamation. The Forest Service is responsible for the management of mineral materials such as rock, sand, and gravel on National Forest System lands.

A number of other agencies, such as the Department of Energy, the Department of Commerce, and the Federal Emergency Management Agency, play roles in the establishment of minerals policy.

States with significant mineral resources also have their own state agencies that oversee minerals management on state-owned and private lands.

Minerals and Indicator Minerals

For the purpose of this analysis of the minerals situation in the United States, minerals have been placed in three broad categories.

1. Energy minerals. These include the fossil fuels coal, oil and gas, and oil shale, as well as other earth resources that provide power such as uranium and geothermal resources.
2. Metallic minerals. These include metallic minerals such as iron, aluminum, chromium, cobalt, molybdenum, copper, lead, gold, and silver. Metallic minerals are essential to many consumer products and industrial processes, and are used in high-technology weapons systems.
3. Industrial minerals. This is a broad category that includes minerals used in industrial processes, construction, agricultural applications, and personal adornment. Industrial minerals include limestone used for metallurgy and cement manufacturing; mineral materials such as sand, gravel, and crushed stone used in road and building construction; phosphate rock used as fertilizer; and gemstones such as diamonds and emeralds.

Major minerals categories and subcategories are shown in table 2.

To simplify the analysis in this assessment of the nation's minerals situation, 13 minerals have been selected as "indicator minerals." These are minerals that have attributes and uses common to other minerals in their class, have common location and market characteristics, and are found in significant amounts in the United States and on national forests. The indicator minerals for each of the three categories are:

1. energy minerals: oil, natural gas, coal, geothermal resources, and uranium;
2. metallic minerals: copper, lead, molybdenum, gold, and silver; and
3. industrial minerals: phosphate rock, limestone, sand, and gravel.

TRENDS IN CONSUMPTION OF MINERALS AND PROJECTED DEMAND

Highlights

- The U.S. is among the world's leaders in important mineral consumption.
- Demand for energy peaked in 1979 and decreased dramatically. However, since 1983 energy use has increased at a moderate rate.
- Demand patterns for metallic minerals vary with the mineral, but there has been a fall-off since 1970. Some consumers have switched to cheaper, non-metal substitutes.
- Demand for energy minerals is expected to increase moderately, with a decrease in the use of oil and an increase in the use of coal.
- Demand for individual metallic minerals is volatile but expected to increase at a modest rate through 2040. High demand growth is expected for scarce and costly specialty metals, such as the platinum-group metals.
- Although the U.S. is a mineral-rich nation, it imports significant quantities of some minerals—especially petroleum.

Table 2.—Categories of mineral resources.

METALS

Metals Used in Iron Alloys

Iron
Chrome
Cobalt
Columbium
Manganese
Molybdenum
Nickel
Tantalum
Tungsten
Vanadium

Base Metals

Antimony
Bismuth
Cadmium
Copper
Lead
Tin
Zinc

Light Metals

Aluminum
Beryllium
Magnesium
Titanium

Precious Metals

Gold
Platinum Group
Silver

Other Metals

Mercury

Minor Metals

Arsenic
Boron
Bromine
Carbon
Cesium
Chlorine
Fluorine
Germanium
Graphite
Indium
Rhenium
Rubidium
Scanium
Selenium
Tellurium
Thallium

NONMETALLIC INDUSTRIAL MINERALS

Building Material

Gypsum
Limestone
Perlite
Sand & Gravel
Stone, Crushed
Stone, Dimension

Fertilizers

Guano
Limestone
Phosphate
Potash

Insulation

Asbestos
Mica
Vermiculite

Pigments and Fillers

Barite
Bentonite
Clays
Kaolin
Talc

Abrasives

Corundum
Flint
Garnet
Industrial Diamonds
Pumice
Tripoli

Gem Stones

Beryl
Diamond
Emerald
Opal
Sapphire

Ceramic Materials

Calcite
Common Clays
Feldspar
Fluorspar
Glass Sand
Quartz

Decorative Stones

Granite
Marble
Obsidian
Petrified Wood
Slate
Travertine

Minor Industrial Minerals

Greensand
Meerschaum
Staurolite
Wollastonite
Quartz Crystal
Strontium
Zeolites

Diverse Uses

Lithium
Salt
Silicon
Sodium
Sulfur

ENERGY SOURCES AND GASES

Coal
Natural Gas
Petroleum
Shale Oil
Synthetic Gas
Argon
Carbon Dioxide
Helium
Hydrogen
Neon
Nitrogen
Oxygen
Geothermal

Other

Amber
Fossil Plants, Animals
Peat

RARE EARTH METALS

Cerium
Dysprosium
Erbium
Europium
Gadolinium
Holmium
Lanthanum
Lutetium
Neodymium
Praseodymium
Promethium
Samarium
Terbium
Thulium
Ytterbium

RARE EARTH MINERALS

Bastnasite
Doverite
Euxenite
Fergusonite
Gadolinite
Monazite
Samarskite
Xenotime

SOURCES: McDivitt and Manners 1974, USDI BM 1979.

- The trend is toward the increase of oil imports, although the U.S. has abundant supplies of coal that could substitute for foreign oil. Some experts say there are significant untapped domestic supplies of oil that could be exploited if prices were favorable.
- For those U.S. metallic minerals in reserve, future trends in imports will depend on the production costs of domestic minerals relative to the price of overseas supplies.

The United States is among the world's leaders in the consumption of many important minerals (tables 3 and 4). With 5.8% of the world's population, Americans consume more than 30% of the world's annual production of natural gas, nearly 26% of the petroleum, 28% of the molybdenum, 27% of silver, and more than 21% of lead and copper. However, other industrialized nations, notably Japan and West Germany, equal or surpass the United States in per capita consumption of some metallic minerals such as copper and iron. There will be increased demand for minerals in world markets as less developed nations industrialize.

National economic activity as reflected by gross national product, in addition to population growth, have some influence over minerals consumption and are expected to increase through 2040 (fig. 1). However, increases in GNP and population do not necessarily mean a proportionate increase in minerals use. Since 1960, energy use per dollar of GNP has steadily declined, probably reflecting the mix of fuels (coal, nuclear, gas, and oil) used to generate electricity, combined with increased efficiency in generating equipment and manufacturing machinery (US DOE 1985). Likewise, per capita consumption of the traditional "tonnage metals" like copper, lead, and iron are declining (Sousa 1987). Changes in the structure of the nation's economy, such as a continuation of growth in the service and communications sectors and decline in energy-intensive manufacturing, could moderate increases in the use of energy and metallic minerals in the manufacture of durable consumer products and industrial machinery. However, significant growth in manufacturing and construction is expected even though those sectors are expected to decline in importance relative to other sectors of the economy (USDA FS 1986a).

Technology also is a factor in minerals consumption through development of new consumer products made with minerals, new processes that permit substitution of renewable materials, processes and products that use energy and minerals more efficiently, and processes that facilitate recovery and recycling. Thus, as technology reduces the amount of metallic minerals and mineral materials required, it also generates new uses and demand for minerals. There is a growing demand for specialty metals used as alloys or in the manufacture of composite materials (Sousa 1987).

Finally, demand also is affected in ways that are unpredictable by changes in social values, such as concerns over toxic materials.

When trends in minerals consumption are examined, the price of minerals in a world minerals market cannot be ignored. World market prices affect the competitive position of the domestic minerals industry by influencing manufacturers' decisions about where they buy the minerals they use. Price also influences consumers' decisions about whether and what to buy and affects overall demand. How prices influence supply is discussed in the Minerals Supplies section below.

Table 3.—U.S. consumption vs. world consumption, 1983.

Commodity	Units	Domestic consumption	World consumption	US % of world total
FUELS				
Petroleum	million barrels/day	15.23	58.76	25.9
Natural gas	billion cubic feet	16,835	54,388	30.9
Coal[1]	trillion Btus	15,900	79,796	19.9
NON-FUELS[2]				
Metals				
Copper	thousand metric tons	2,020	9,520	21.2
Gold	thousand troy oz.	3,060	40,000	7.6
Lead	thousand metric tons	1,141	5,240	21.7
Molybdenum	million pounds	43	152	28.2
Silver	million troy oz.	118.4	428.0	27.6
Materials				
Limestone	thousand short tons	14,902	119,147	12.5
Phosphate	thousand metric tons	34,830	135,000	25.8
Sand, gravel	million short tons	619	8,100	7.6

[1]*Coal figures are given in British Thermal Units (BTUs) because the energy content of a ton of coal varies worldwide. In the United States in 1983, 736.7 million short tons of coal were consumed.*

[2]*Non-fuel mineral consumption is called "demand."*

Sources: USDI BM 1985, US DOE 1987a.

Table 4. Demands for selected minerals and energy, 1955 to 1985, with projections to 2040.

Year	Population	Gross national product	Total energy consumption	Total demand							
				Copper	Lead	Gold	Silver	Molybdenum	Lime	Sand and Gravel	Phosphate Rock
	(millions)	(bill. 87$)	(quad Btu)	(1000 metric tons)		(million troy oz.)		(million lbs.)	(million short tons)		(million metric tons)
1955	165.9	1,767.4	38.82	1,637	1,100	1.3	101.4	38.8	10.5	592	11.1
1965	194.3	2,468.2	52.68	1,982	1,126	5.3	137	68.1	16.8	907	19.5
1975	216	3,174.5	70.55	1,473	1,176	4	153.2	90	19.1	761	31.0
1977	220.2	3,497.9	76.29	2,035	1,435	5.3	123.9	61.4	20.3	926	34.5
1978	222.6	3,774.4	78.09	2,333	1,433	5.1	148.1	67.7	21	992	36.8
1979			78.9	2,433	1,358	5.1	130.6	73.7	21.5	945	39.6
1980	227.8	3,768.1	75.96	2,175	1,070	3.6	91.2	60.6	19.4	762	40.8
1981	230.1	3,841.1	73.99	2,278	1,167	3.5	168.6	61.1	19.3	689	35.1
1982	232.5	3,743.2	70.84	1,761	1,075	3.7	150.1	31	14.4	593	28.8
1983	234.8	3,872.3	70.5	2,014	1,148	3.3	174.8	39	15.1	653	34.8
1984	237	4,128.6	74.06	2,107	1,207	3.4	169.1	41	16.1	772	41.8
1985	239.3	4,224.9	73.96	2,144	1,148	3.4	160	45.4	15.9	798	36.4
1990	249.7	4,780	78.6	2,300	1,300	5.3	140	66	19.2	750	39
2000	268	6,331	87.3	2,800	1,600	6.7	150	71	27.5	1,000	47
2010	283.2	8,052	88.47	3,379	1,820	8.4	162	76	39.5	1,330	56
2020	296.6	10,071	93.15	4,079	2,072	10.7	175	83	56.8	1,771	67
2030	304.8	12,011	97.83	4,923	2,358	13.6	190	90	81.6	2,357	80
2040	308.6	14,214	102.51	5,942	2,683	17.3	206	97	117.4	3,138	95

Index of economic indicators, and demand growth in energy and indicator non-fuel minerals, 1977–2040.

Year	Population	Gross national product	Total energy consumption	Copper	Lead	Gold	Silver	Molybdenum	Lime	Sand and Gravel	Phosphate Rock
1977	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1978	101.1	107.9	102.4	114.6	99.9	96.2	119.5	110.3	103.4	107.1	106.7
1979	0.0	0.0	103.4	119.6	94.6	96.2	105.4	120.0	105.9	102.1	114.8
1980	103.5	107.7	99.6	106.9	74.6	67.9	73.6	98.7	95.6	82.3	118.3
1981	104.5	109.8	97.0	111.9	81.3	66.0	136.1	99.5	95.1	74.4	101.7
1982	105.6	107.0	92.9	86.5	74.9	69.8	121.1	50.5	70.9	64.0	83.5
1983	106.6	110.7	92.4	99.0	80.0	62.3	141.1	63.5	74.4	70.5	100.9
1984	107.6	118.0	97.1	103.5	84.1	64.2	136.5	66.8	79.3	83.4	121.2
1985	108.7	120.8	96.9	105.4	80.0	64.2	129.1	73.9	78.3	86.2	105.5
1990	113.4	136.7	103.0	113.0	90.6	100.0	113.0	107.5	94.6	81.0	113.0
2000	121.7	181.0	114.4	137.6	111.5	126.4	121.1	115.6	135.5	108.0	136.2
2010	128.6	230.2	116.0	166.0	126.8	158.5	130.8	123.8	194.6	143.6	162.3
2020	134.7	287.9	122.1	200.4	144.4	201.9	141.2	135.2	279.8	191.3	194.2
2030	138.4	343.4	128.2	241.9	164.3	256.6	153.3	146.6	402.0	254.5	231.9
2040	140.1	406.4	134.4	292.0	187.0	326.4	166.3	158.0	578.3	338.9	275.4

NOTE. Non-fuel mineral projections are based on the average annual growth rate between 1983 and 2000, as calculated by the Bureau of Mines U.S. Department of the Interior. 1990 and 2000 energy consumption projections are by DOE, 2010–2040 are based on linear regression analysis by Forest Service.

Sources: USDI BM 1981, 1984, 1985, 1987b; US DOE 1987a; USDA FS 1986b

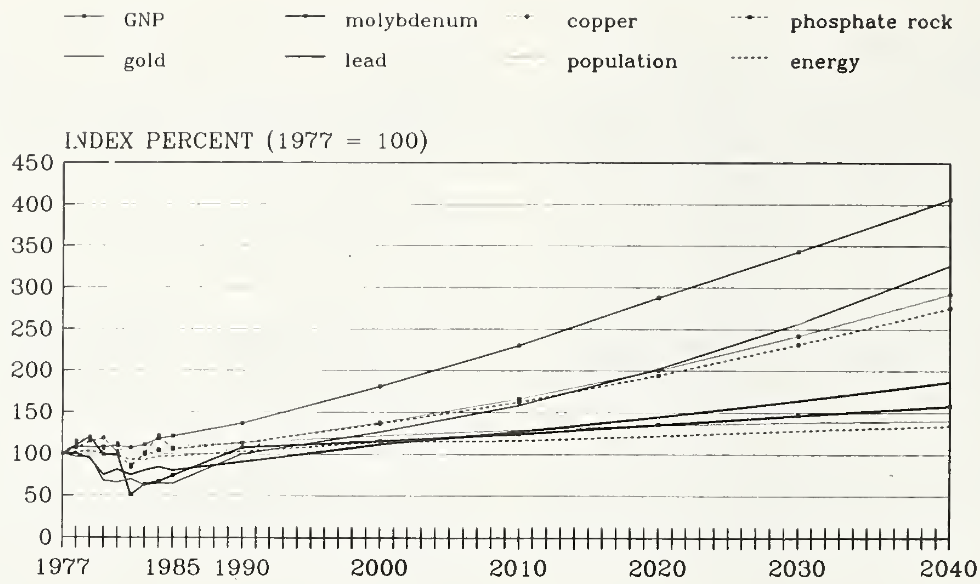

Figure 1.—Index of demand for selected minerals, energy consumption, GNP and population, projections to 2040.

Past and Current Consumption Trends

Energy Minerals

Following World War II, annual domestic consumption of all sources of energy, particularly fossil fuels, increased steadily until 1974, when the Organization of Petroleum Exporting Countries (OPEC) raised oil prices and limited production (table 5). After a significant drop in energy consumption in the mid-1970s, consumption turned upward and peaked in 1979 at under 79 quadrillion British thermal units (quads). There was an abrupt decline in energy use to 70.5 quads in 1983, and since that time consumption has climbed moderately, to 73.9 quads in 1986 (table 6) (US DOE 1987b). Recent demand has been moderated by conservation measures and increased use–efficiency in combination with the decline of energy-intensive heavy industry.

Residential and commercial use accounted for the largest share of energy consumption in 1986—27.25 quads. Industry consumed 25.98 quads, and the transportation sector, 20.69 quads. Electric utilities, energy's middleman, consumed 26.79 quads (US DOE 1987b).

Between 1977 and 1986, each sector's share of total domestic energy consumption changed. The residential-commercial and transportation sectors registered increases (3.6% and 2.0%, respectively), while the industrial sector's share fell a corresponding 5.6%. Electrical utilities consumed 6.5% more energy in 1986 than in 1977 (US DOE 1987b).

Since its inception in 1859, the modern petroleum industry grew at a rapid rate until the late 1970s, spurred in this century by the advent and ever-broadening use of automobiles. At the turn of the century, the United States used 60 million barrels of oil a year; in 1978, Americans consumed almost 7 billion barrels. In less than four generations, U.S. petroleum consumption multiplied more than 100 times, while population only tripled in size (Resources for the Future 1960, US DOE 1987b) Over the past decade, however, the United States has turned increasingly to its abundant coal reserves as a source of energy; between 1977 and 1985, consumption of both petroleum and natural gas declined, while consumption of coal increased 24% (table 6). From 1975 to 1985, the portion of the Nation's energy provided by coal grew from 17.9% in 1975 to 23.6% in 1985. Meanwhile, oil's share of the Nation's energy use fell from 46.4% to 41.8% and that of natural gas from 28.3% to 24.1%.

After sharp growth in the number of nuclear reactors and electricity generated in the early and mid-1970s, nuclear power generation fell late in the decade, hitting a low in 1980. Since 1980, the number of on-line reactors and the amount of power generated have increased (US DOE 1987c). Although nuclear power generation more than doubled between 1975 and 1985, it still provided only 4.15 quads of energy in 1985 (table 6), some 15.5% of all electrical power generated that year. Since 1974, orders for 117 nuclear power plants have been canceled, primarily because of high construction costs, reduced demand, and because it has been cheaper to generate electricity with coal (US DOE 1987c).

Geothermal resources used for electrical generation supply less than three-tenths of 1% of the nation's energy (10.3 million kilowatt hours in 1986), although geothermal power generation has increased about 275 percent from 1977 to 1986 (table 6).

Table 5. Trends in domestic fossil fuel consumption 1949–1985.

Commodity	Unit	1949	1955	1965	1975	1985
Petroleum	mil. barrels per day /quadrillion Btu	5.76/11.88	8.46/17.25	11.51/24.40	16.32/32.73	15.73/30.92
Natural gas	trillion cubic feet /quadrillion Btu	4.97/5.15	8.69/9.00	15.28/15.77	19.54/19.95	17.28/17.85
Coal	million short tons /quadrillion Btu	483.2/11.98	447.0/11.17	472.0/11.58	562.6/12.66	818.0/17.48
TOTAL	quadrillion Btu	29.01	37.42	51.75	65.34	66.25

Source: US DOE 1987a.

Table 6.—Consumption of energy (quadrillion Btu) by source, 1977–1986, with projections to 2000[1]

Source	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1995	2000
Petroleum	37.12	37.97	37.12	34.2	31.93	30.23	30.05	31.05	30.92	31.89	32.2	31.7	31.7	31.8	32.6	34.7
Natural gas	19.93	20.00	20.67	20.39	19.93	18.51	17.36	18.51	17.85	16.53	17.4	17.9	17.8	18.1	18.6	18.5
Coal	13.92	13.77	15.04	15.42	15.91	15.32	15.90	17.07	17.48	17.32	17.8	18.5	18.7	19.1	21.7	23.6
Nuclear	2.7	3.02	2.78	2.74	3.01	3.13	3.20	3.55	4.15	4.48	4.9	5.4	5.7	6.0	6.4	6.7
Hydropower	2.51	3.14	3.14	3.12	3.11	3.56	3.87	3.72	3.36	3.50	([3])					
Other	0.02	0.13	0.07	–0.03	–0.01	–0.02	–0.01	([2])	([2])	([2])	3.8	3.5	3.6	3.6	3.8	3.9
Geothermal	0.08	0.06	0.08	0.11	0.12	0.10	0.13	0.16	0.20	0.22	([3])					
Total	76.29	78.09	78.9	75.96	73.99	70.84	70.50	74.06	73.96	73.93	76.1	77.0	77.5	78.6	83.1	87.

Notes:
[1]*Projection figures are the Department of Energy's "base case forecasts."*
[2]*Less than 0.005 quadrillion Btu.*
[3]*Forecast figures for "other" sources of energy include geothermal and hydropower.*
Sources: US DOE 1987a, 1987b.

Metallic Minerals

Demand patterns in the metals industry vary from metal to metal. In general, consumption of metallic minerals rises and falls in consonance with domestic and worldwide economic prosperity and recessions, and periods of relative peace and military conflict. This is because metals contribute many of the primary materials for consumer products like cars and homes, and military weapons systems. The substitution of industrial minerals like carbon and glass, as well as plastics, in products traditionally made of metal has contributed to a general decline in demand since 1970. However, metallic minerals producers have become more cost-competitive in recent years, and traditional mineral commodities such as iron, lead, and copper are expected to maintain a steady share of the market and realize modest growth (Sousa 1987). Meanwhile, there is the prospect for high demand growth for high value specialty metals, such as the platinum-group minerals, for use in advanced metal alloys and tough, heat-resistant, and lightweight composite materials. One analyst says that ". . . all signs seem to point to a transition of some kind: from a largely undifferentiated commodity metals (and plastics) economy to one in which more highly specialized and technology-intensive materials play an increasingly important role" (Sousa 1987). While the use of precious metals in jewelry and industrial applications generate most of the demand for gold and silver, the psychology of individuals who buy the metals as a financial investment is an important factor. Recent trends in demand for the indicator minerals are shown in table 7 and are discussed below.

Copper.—Over the past 15 years (1972–1987), copper consumption has averaged 2.1 million tons, rising and falling with the economic cycles. Consumption ranged from a low of 1.5 million tons (1975) to a high of 2.4 million tons (1979); in 1987, consumption was 2.2 million tons. The recovery of the mid-1980s following the 1982 recession and inventory build-up (coupled with reduced domestic production) caused a drastic reduction in inventories, and the price for copper (which had been depressed) rose dramatically at the end of 1987. The automobile, housing, and appliance market all expanded and the demand for copper rose. Substitutes have made significant inroads into traditional copper markets and have limited its demand growth. Aluminum, because it is lighter, has challenged copper's dominance in

overhead transmission lines; while drainage pipes, once a major use of copper, now are predominantly made of plastic. Conversely some markets, including automobiles and roofing, have expanded usage (Edelstein 1988).

Lead.—The demand for lead has declined since the late 1970s, but has leveled-off in the 1980s, and is expected to slightly increase into the next century as innovative uses for industrial and commercial traction batteries more than offset its elimination in gasoline. In 1983, lead's use in storage batteries accounted for 73% of total domestic consumption (USDI BM 1985). There has been an increasing demand for lead to shield radiation from television sets and computer video display terminals (Latimer 1987), although the overall health of the industry still depends on demand for starting-lighting-ignition batteries. Recycled lead accounts for about 50% of annual domestic consumption—the highest recycling rate for any metal except antimony (USDI BM 1987b).

Molybdenum.—Molybdenum is used primarily as an alloy agent in steel and cast iron to enhance hardness, strength, and corrosion resistance. Its versatility guarantees a continued demand for the metal, but levels of domestic consumption depend to a great extent on its major market, the steel industry. Since the early 1960s, molybdenum has experienced a domestic annual demand increase of under 1%, but with many peaks and valleys (USDI BM 1985). Demand for molybdenum—both domestically and worldwide—hit its high point in 1979 and sank to an all time low in 1982. Recently, molybdenum has been threatened by a cheaper alloy substitute and trend toward the use of plastics instead of steel (Blossom 1987).

The United States is the major world supplier of molybdenum, exporting more than 50% of domestic production. Because of the desirability of selling the metal overseas to help the Nation's balance of payments, overseas demand must be considered a complement to domestic demand. Although exports have declined for the past decade, the United States exported more than 55 million pounds of molybdenum in 1986 (USDI BM 1987b).

Gold.—Jewelry has always been the most important end use for gold, although industrial uses burgeoned as the electronics industry grew in the 1950s and 1960s. Since 1975, jewelry has accounted for over one-half of all domestic gold consumption, despite high prices in 1980–83. Industrial applications, mostly in electronics, account for 32% of demand. During the last 20 years, dentistry has accounted for 10% to 15%, of demand. Since legalization of private ownership in 1975, consumption of gold in coins, medallions, and other items purchased as investments has amounted to as much as 6% of annual demand. However, investment demand has fluctuated wildly, ranging from a high of 268,000 troy ounces in 1977 to a low of 4,000 troy ounces in 1983, which testifies to the unpredictability of investor psychology.

Silver.—Since 1967, photographic materials have constituted the largest domestic use of silver, followed by the electrical and electronics industry. Almost 7% of use is for jewelry. Domestic consumption peaked in 1973 at 197 million ounces and has since declined, amounting to 118.6 million ounces in 1985 (USDI BM 1985).

Industrial Minerals

Limestone.—Limestone, used primarily as a construction aggregate, is also used for chemical and industrial purposes, steel furnaces, and to reduce particulate emissions from industrial smokestacks, among other uses. Demand and production were steady in the 1970s, but in the early 1980s demand dropped to 75% of the consumption level the decade before.

Phosphate Rock.—The fertilizer industry is the major consumer of phosphate. The domestic fertilizer industry is considered to be mature; little growth is expected given consolidation and some reduction in the agriculture industry. Over the past 10 to 15 years, domestic demand has declined and production facilities have shut down or consolidated. However, two-thirds of annual phosphate rock production is exported, and foreign markets are strong.

Table 7. Trends in domestic non-fuel indicator mineral consumption, 1949–1985.

Commodity	Unit	1949	1955	1965	1975	1985
METALS						
Copper[1]	thousand metric tons	1,056	1,637	1,982	1,473	2,144
Gold[2]	million troy oz.	[3]3.1	1.3	5.3	4.0	3.0
Lead[2]	thousand metric tons	868.8	1,100.1	1,126.3	1,176.7	1,148.3
Molybdenum[2]	million pounds	[3]21.3	38.8	68.1	90.0	33.5
Silver[2]	million troy oz.	97.7	101.4	137.0	153.2	118.6
MATERIALS						
limestone	million short tons	6.3	10.5	16.8	19.1	15.7
phosphate[1]	million metric tons	7.7	11.1	19.5	31.0	36.4
sand and gravel	million short tons	319	592	907	761	799

Notes:
[1]*Apparent consumption*
[2]*Reported consumption*
[3]*Average 1946–1950*
Sources: USDI BM 1977, 1987a, 1987b.

Sand and Gravel.—From the end of World War II until the mid-1960s, the demand for sand and gravel steadily increased at an annual rate of about 8%. Growth slowed and in the early 1980s demand declined to about 590 million short tons. In 1982, demand for sand and gravel reflected the fortunes of the construction industry which, during the 1970s and the early 1980s was battered by inflation, high interest rates, effects of the OPEC oil embargo, and general economic recession. Since 1982, consumption has grown to more than 800 million tons. The United States exports a small amount of sand and gravel (USDI BM 1985, 1987b).

Projected Trends in U.S. Demand

Energy Minerals

The *Annual Energy Outlook* published by the Department of Energy's Energy Information Administration projects energy demand only to the year 2000. Its base case consumption forecasts for selected years through 2000 by energy source are shown in table 8.

In order to project energy demand to 2040, as required for this assessment, an energy supply demand model developed by Jae Edmunds and John Reilly (1986), Institute for Energy Analysis, Oak Ridge Associated Universities, was used. The model, developed for the Department of Energy, projects long-term production of atmospheric carbon dioxide from consumption of worldwide energy. The model projects consumption of energy from oil, gas, solids (encompassing coal and biomass), and nuclear energy at decade intervals through the year 2050. Since the model's benchmark year differed from this assessment, a trend line was developed and used to establish projected demand levels for the assessment's benchmark years. The projected demand for the four categories of energy, in Btu and units by which each commodity is traditionally measured, is shown in table 9.

The price of energy, discussed in detail in the section on minerals supplies, will have a major influence on demand and the sources Americans tap for their energy. Rising oil prices could stimulate a shift to use of domestic coal and biomass-based fuels, including wood. Moreover, increased prices for oil could make production of synthetic fuels (gas from coal and gasoline substitutes from corn and other vegetable substances) and the use of alternative energy sources, such as solar and wind, economically viable.

Some authorities believe the nation is in a period of transition from reliance on fossil fuels—especially petroleum and natural gas—to substantial use of renewable energy sometime in the next century. Under this scenario, rising prices and uncertain supplies of petroleum will lead to increased use of coal and a concentrated effort to develop renewable energy technologies (Backus 1981).

Metallic Minerals

To project long-term demand for any specific metallic mineral is difficult because domestic demand is influenced by many factors, some that relate to economic and social developments in the United States, others to world economic, political, and military events that influence levels of supply and consumer prices.

As with energy minerals, demand for metallic minerals has been linked to population growth, gross national product, and disposable incomes. The vigor of the domestic durable goods manufacturing sector, communications, and defense industries have a bearing on the domestic demand for metallic minerals. The demand for gold and silver is largely influenced by the world price of these precious metals.

The Bureau of Mines has projected consumption of some important minerals to the year 2000, based on analysis of trends in GNP, gross private domestic investment, Federal Reserve Board production indices, and

Table 8.—Summary of projected base case energy consumption.

	1987	1988	1989	1990	1995	2000	Annual rate of change 1987–2000
	quadrillion Btu						(percent)
Petroleum	32.6	33.0	33.4	33.7	35.1	36.3	0.8
Natural Gas	17.4	17.4	17.8	17.8	18.9	20.2	1.2
Coal	18.0	18.0	18.3	18.8	20.8	22.6	1.8
Nuclear	4.9	5.3	5.5	5.9	6.3	6.4	2.1
Hydropower/Other[1]	3.3	3.5	3.7	3.8	3.9	4.1	1.6
Total	76.2	77.2	78.7	80.0	85.0	89.6	1.3

[1] *Includes industrial generation of hydroelectricpower, net electricity imports, and electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems.*

Source: US DOE 1987a.

Table 9. Projections for energy demand through 2040.

Commodity	Units	1987	1991	1995	2000	2005	2040
Coal	Quadrillion Btu	22.99	25.96	29.19	33.22	29.93	37.67
	Billion short tons	1.04	1.18	1.33	1.51	1.36	1.71
Oil	Quadrillion Btu	27.56	28.63	29.69	31.01	31.94	36.28
	Billion barrels	4.75	4.93	5.11	5.34	5.50	6.25
Gas	Quadrillion Btu	16.83	15.74	14.65	13.29	15.25	25.81
	Trillion cubic feet	16.29	15.23	14.18	12.86	14.76	24.98
Nuclear	Quadrillion Btu	4.67	5.55	6.43	7.53	8.47	14.51
	Billion kilowatt-hours	432.04	513.46	594.87	696.64	783.60	1342.39

Note. The figures in quads were derived from the Edmunds model. To calculate demand in units by which each commodity is traditionally measured, Department of Energy's thermal conversion rates were used. For coal, the average heat content of all coal in 1986 was 21.932 million Btu short ton. Edmunds' projections are for biomass solids, a major part of which are coal. We subtracted 10% of the projected biomass demand to calculate coal demand after the year 2000. For oil, the thermal conversion factor used was 5.800 million Btu/barrel. For gas, the heat content calculated was 1,033 Btu/cubic foot. For nuclear power plant generation, DOE used the weighted annual average heat rate for nuclear steam-electric plants in the U.S., which was 10,809 Btu/kilowatt-hour in 1986.
Sources: Edmunds and Reilly 1986, US DOE 1987b.

population growth. For purpose of this assessment, the Bureau of Mines' projections of average annual probable demand through 2000 for the indicator minerals (table 10, fig. 1) were extended to 2040. These projections provide a picture of what future demand might be *if present trends continue*. For example, the Bureau of Mines projects the demand for copper to grow at an average annual rate of 1.9% through 2000. By projecting this to 2040, the domestic demand for copper would increase from the 2.1 million metric tons consumed in 1985 to 5.9 million metric tons. Similarly, at a 2.4% average annual growth rate, domestic consumption of gold would increase from 3.0 million troy ounces in 1985 to 17.3 million troy ounces in 2040. However, it is impossible to anticipate technologies that may have a profound influence on consumption of individual minerals. Some of the factors expected to affect future demand are discussed below. Except where otherwise noted, the discussion is drawn from *Minerals Facts and Problems, 1985 edition* (USDI BM 1985).

Copper.—Because of its use in construction, manufacturing, and communications, copper's fortunes depend to a large degree on the health of the Nation's economy. Modest growth that amounts to 1.9% annually is projected through 2000. Copper will face increased competition from substitutes in some markets, but new uses in electronics and communications, and the recapture of some older markets in construction and transportation, are projected to more than offset losses. Nearly 60% of the forecast for probable total end-use demand for copper in the year 2000 is in electrical products. Growth in this sector, copper's most important market, closely matches projections of gross private domestic investment. Copper's use by the electrical and electronics industry is not expected to decline further before 2000, and use by the construction sector is expected to increase somewhat as copper roofing and other uses are revived. A significant portion of domestic demand for copper has been met by the recovery of old scrap, which has averaged 35% of total domestic demand for more than half a century. This proportion is not expected to grow much before 2000. Scrap recovery diminishes during periods of low prices, and the international availability of inexpensive primary copper discourages recycling.

Lead.—Trends in demand for lead are linked strongly to growth of the auto industry; 75% of lead production is used in automobile batteries. Past demand for lead has matched growth in GNP, and projections for a moderate but steady growth in demand averaging 1.3% annually through the year 2000 is linked to projected growth in GNP. Increased use of lead by the electronics industry and recapture of the lead cable sheathing market should contribute to a rising demand for lead.

Molybdenum.—Some 75% of molybdenum production is used as a steel alloy, and the fortunes of the steel industry, both domestically and in other countries, will largely determine demand for molybdenum. Prevailing demand patterns plus some growth in demand for specialty steels containing molybdenum alloy are expected to continue through the end of the century. This will contribute to a modest but stable overall demand growth of under 1% a year through 2000. Since the majority of domestic production of molybdenum is exported (62% in 1986), overseas industrial development will play a significant role in global demand for molybdenum (USDI BM 1987b).

Gold.—The demand for gold is projected to grow at an average annual rate of 2.4% until 2000. Gold demand is influenced strongly by the world price of the metal. Demand for gold in the form of jewelry and luxury items—more than one-half of gold's market—responds to the metal's world price, rather than changes in GNP or population. Demand for gold in dentistry, expected to comprise about 10% of gold's market in the year 2000,

Table 10. U.S. total demand projections in the year 2000.

Commodity	Units	Low	High	Probable	Average annual growth rate 1983–2000 (percent)
METALS					
Copper	1,000 mton	2,400	3,500	2,800	1.9
Gold	1,000 oz.	5,000	8,300	6,700	2.4
Lead	1,000 mton	1,100	2,200	1,600	1.3
Molybdenum	mil. lb.	60	100	71	0.8
Silver	mil. oz.	120	180	150	0.8
MATERIALS					
Limestone	1,000 ston	21,900	35,200	27,500	3.7
Phosphate	1,000 mton	45,000	50,000	47,000	1.8
Sand and gravel	mil. ston	650	1,230	1,000	2.9

Source: USDI BM 1985.

will be influenced by the development of substitutes, improved oral hygiene, and the possible advent of government programs that would expand access to dental care. Projected growth in the electronics component industry—gold's other major market—depends on trends in equipment longevity, substitution, and discovery of new industrial applications. Increased demand for gold investment products is expected to be minimal.

Silver.—Only moderate growth in the demand for silver—eight-tenths of 1% as an annual average—is anticipated over the next decade as industries that use silver in manufacturing consume less silver per product unit and as substitutes increase their market share. Improved recovery methods for used silver are expected to further dampen the demand for newly-mined metal. The trend toward substitutes and increased use-efficiency is expected to affect foreign markets as well as domestic, although larger demand growth is projected for the rest of the world, not for the United States.

Industrial Minerals

Limes.—The chemical and industrial sector is the biggest user of lime, the commodity produced from limestone. In 1983, the chemical and industrial sector used 10 times the amount of lime as the construction industry, limestone's second biggest market. By 2000, the amount of limestone used for chemical and industrial purposes is projected to nearly double 1983 consumption levels—to 24.6 thousand short tons or nearly 90% of domestic consumption. These estimates are based on a projected 1.8% growth in the iron and steel industry, and an expected increase in demand for lime in the environmental sector—for use in cleaning smoke stacks, sewage treatment, and land reclamation. Demand for lime in agriculture is expected to remain even. The projected 3.7% annual average growth in the demand for limestone is based almost exclusively on expected growth in the chemical and industrial sectors.

Phosphate Rock.—Projections for increased demand for phosphate rock in the year 2000 are based primarily on the expectation that there will be growth in both the export and domestic markets. The Bureau of Mines projects probable average annual growth in these two markets through the year 2000 at 1.8%. The U.S. share of world phosphate sales is expected to decline because the U.S. phosphate industry will slowly lose its ability to supply its markets as reserves are depleted. There will be a significant increase in supply from North African and Middle Eastern countries that will replace lost production in the United States and help supply the forecasted increase in demand.

Sand and Gravel.—Current trends and end-use shares are expected to continue. Between 1974 and 1983, 45% of all sand and gravel was used for concrete aggregates and concrete products. Increased use of crushed stone as a substitute for sand and gravel in concrete, asphalt, and road-base uses is expected to significantly affect demand for sand and gravel. An important factor in substitution decisions are safety regulations and environmental restrictions. Delivery costs increase the end-user prices and encourage the search for substitutes like crushed stone.

Trends in Minerals Imports

Although the United States is a mineral-rich nation, it imports significant quantities of some minerals. Oil is imported to supplement domestic supplies. Some minerals are imported even though there are active mines in the United States because it is cheaper to buy overseas than to develop and produce domestic supplies. Other metallic minerals are imported because the minerals do not occur in the United States in sufficient quantities or domestic resources are uneconomic given current prices and technology.

However, the United States also exports significant amounts of some minerals. The United States is the world's major supplier of molybdenum, exporting 59 million pounds of the 94 million pounds produced in 1986 (USDI BM 1987b). Less than 1% of domestic production of limestone rock (2.8 million tons of the 770 million tons produced) was exported in 1986. The United States also exports significant amounts of some minerals that it also imports in large quantity. For example, in 1986, the United States imported 16.7 million tons of iron ore, produced 38.8 million tons, and exported 4.5 million tons. In 1986, the United States exported $24 billion worth of nonfuel minerals. The United States also is a major international supplier of coal, marketing $3.9 billion overseas in 1986 (US DOE 1987a). Though it imports more than half of the petroleum consumed domestically, the United States sold petroleum products worth $3.5 billion overseas in 1986.

Energy Minerals

The Nation's oil imports rose steadily from 1960 to 1977 when imports accounted for nearly one in every two barrels of oil (46%) consumed in the United States (about 8.6 million barrels a day). U.S. reliance on foreign oil fell to 27.3% of consumption (4.3 mbd) in 1985, then increased to 32.8% (5.3 mbd) in 1986 (table 11). The National Energy Plan projects foreign oil to account for 16% of U.S. consumption (8.3 mbd) in 2010. Other observers expect far heavier U.S. reliance on foreign oil, perhaps exceeding 50% of domestic consumption by 1991 if present trends in U.S. consumption and production persist (Abelson 1987, US DOE 1987e). However, the United States has abundant supplies of coal, oil shale, and natural gas that could replace imported oil in some cases, depending on technology and the economics of production. There is some evidence that significant supplies of onshore oil remain that could be exploited with new technology (Fisher 1987).

Metallic Minerals

Imports of metallic minerals have fluctuated considerably over the past decade. The percentage of indicator minerals imported is shown in table 12. The United States has consistently imported substantial amounts of copper, lead, gold, and silver. The United States is the world's largest supplier of molybdenum.

For those U.S. metallic minerals in ample supplies, future trends in imports of these minerals will depend in large measure on the cost of domestic minerals relative to the cost of overseas supplies, and on world political and economic factors. Moreover, the strength or

Table 11.—Net fossil fuel imports as a percent of consumption, 1960–1986.

Commodity	1960	1965	1970	1975	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Crude oil	16.5	19.8	21.5	35.8	46.5	42.5	43.1	37.3	33.6	28.1	28.3	30.0	27.3	32.8
Natural Gas	1.2	2.8	3.6	4.5	4.9	4.6	5.9	4.7	4.4	4.9	5.1	4.4	2.5	4.4

Source: US DOE 1987b.

Table 12.—Total net import reliance of indicator non-fuel minerals as a percent of consumption, 1977–1986.

Commodity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
METALS										
Copper	13	20	13	16	6	1	19	23	28	27
Gold	61	53	53	18	15	42	30	37	46	21
Lead	13	9	5	NE	1	11	20	20	13	20
Molybdenum	NE	NE	NE	NE	NE	NE	7*	NE	NE	NE
Silver	31	48	42	7	53	55	59	58	59	71
MATERIALS										
Limestone	2	3	3	2	2	2	2	1	1	1
Phosphate Rock	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
Sand and Gravel	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

"Unusually large decreases in domestic stocks resulted in a positive net import reliance as a percent of consumption." (U.S. Department of the Interior, Bureau of Mines 1987b, p. 106)

NOTE.—"NE" denotes net exporter.

Source: USDI BM 1981, 1984, 1987b.

weakness of the domestic economy relative to other developed nations could lead to policies and programs intended to bolster domestic production and manufacturing. Such a scenario could promote the development and exploitation of domestic mineral reserves. The continued low value of the dollar in relation to the currency of other countries also could make domestic minerals more cost-competitive with foreign minerals and decrease the use of imported minerals. Threats to foreign supplies through armed conflict or political instability in critical source countries, and U.S. policy aimed at maintaining minerals independence could also reduce imports.

Industrial Minerals

The United States does not import significant amounts of industrial minerals materials and is a net exporter of phosphate rock and sand and gravel.

Table 13. Minerals of which the United States is among the top three world producers.

Aluminum	mercury
barite	mica
beryllium	molybdenum
boron	ammonia
bromine	perlite
cadmium	phosphate
cement	quartz crystal
copper	rare earth metals
diatomite	rhenium
feldspar	salt
industrial garnet	silicon
germanium	sodium carbonate
gypsum	sulfur
helium	talc and prophyllite
lime	titanium
magnesium	vermiculite

Source: USDI BM 1987b.

THE NATION'S MINERALS RESOURCES

Highlights

- The Nation is rich in many of the minerals it requires, but there is uncertainty about the extent of the minerals resources.
- While minerals are distributed widely around the Nation, coal is concentrated in the Allegheny Plateau, the Ohio River Valley, and the Great Plains; oil is found mostly in the southwest and south; and many metallic minerals occur predominantly in the upper Lake States and the mountains and valleys of the West.
- Ownership of the Nation's minerals is complex and there is little information on quantities of minerals in public and private ownership.
- The quantity of recoverable oil is uncertain over the long-term, but the Nation has abundant coal reserves, oil shale and tar sands, uranium, and the potential for greater use of geothermal resources.
- The U.S. possesses large quantities of many metallic minerals, although they may not be economical to develop at current prices or with available technology.
- There are large quantities nationwide of minerals materials used in construction, though urban development threatens their availability in some areas.

Because minerals are contained in soil and rock, some at great depths, the extent of the Nation's minerals resources will never be known. While minerals are nonrenewable and thus finite, the reserves generally are expandable through investment in exploration and development, and the development of new techniques for minerals discovery and recovery.

Little is known about the total extent of the Nation's minerals resources (Cameron 1986). Nonetheless, the United States is rich in many of the minerals it requires. In 1986, it was among the top three producing nations worldwide of more than 30 of the 87 minerals monitored by the Bureau of Mines and a major producer of several others (table 13). For many mineral commodities, even for some of those that are imported, the United States has significant known reserves. For example, the domestic reserve base of copper, which the United States imports in significant quantities, is sufficient to last more than 40 years at 1985 consumption rates (table 14). However, there are no economic domestic supplies of some metallic minerals of economic and military importance.

There is disagreement over quantities of recoverable onshore oil in the contiguous United States. However, the United States has abundant supplies of coal, oil shale and tar sands, uranium for nuclear power, and potential for development of additional geothermal resources.

The amount of oil in recoverable domestic reserves, as estimated by the Department of Energy, would last 9 years at mid-1980s production rates. This recoverable reserve base estimate in terms of years of supply is about the same for natural gas. Domestic coal reserves are considerably more extensive—these reserves would last over 500 years at current production rates.

Location

Generally, the areas of highest mineralization are the mountains and basins of the West and the Appalachian chain in the East (fig. 2). However, minerals of economic importance are widely scattered throughout the United States. For example, there are identified iron deposits in all but six states. Moreover, ores predominantly of one mineral often contain another mineral that can be produced economically as a byproduct or co-product. For example, cadmium often is a byproduct of zinc and cobalt is a byproduct of copper and nickel. Coal underlies about 13% of the Nation and occurs in 37 states (U.S. Department of Agriculture, Forest Service [USDA FS] 1979), although the bulk of the Nation's coal reserves

Table 14.—Domestic and world supply, demand and reserve base for non-fuel minerals, 1985.

Mineral	Units	US Mine Production	US Consumption[1]	Reserve Base[2]	Years to Exhaust Reserves[3]	World Mine Production	World Reserve Base	Domestic % of World Reserve Base
METALS								
Copper	1000 mton	1,106	1,906	90,000	47	8,114	556,000	16
Gold	mil. oz.	2.48	2.99	120	40	48.22	1,490	8
Lead	1000 mton	424	1,113	26,000	23	3,390	142,000	18
Molybdenum	1000 lb.	108,409	33,451	11,800,000	353	215,139	26,000,000	45
Silver	mil. oz.	39.4	119	1,800	15	412.3	10,800	7
MINERAL MATERIALS								
Limestone	1000 ston	15,713	15,865	adequate		125,531	adequate	
Phosphate	1000 mton	50,835	36,384	5,200,000	143	151,863	36,000,000	14
Sand and Gravel	1000 ston	829,530	798,800	(4)		not. avail.	(4)	

[1]Usually both reported and apparent consumption figures are given for each commodity. Reported consumption, usually the lesser figure, was chosen for this table since apparent consumption usually includes recycled material.

[2]The "reserve base" constitutes that part of identified resourced which may reasonably become economic to exploit, without assuming current technological or economic standards.

[3]The number of years it will take to exhaust the reserve base at 1985 consumption rates as indicated above.

[4]"The reserve base is controlled largely by land use and/or environmental constraints. Local shortages of sand or gravel are common" (p. 137, USDI BM 1987b)

Source: USDI BM 1987b.

are located beneath the Allegheny Plateau and Cumberland Plateau in the East, the Ohio and Mississippi River Valleys, and the Great Plains (fig. 3). Major oil and gas basins are concentrated in an area that extends from Oklahoma south to southern Texas, the Appalachian basin, with scattered deposits beneath the eastern plateaus and in western basins (fig. 4). Geothermal resources occur mainly in the West (Honig, et al. 1981).

Although deposits of a given mineral commodity may be found in many areas of the nation, production typically is far more limited (USDI BM 1987b, Honig et al. 1981.) For example, although there are deposits of copper throughout the Appalachian Mountains, Missouri, Oklahoma, Michigan, Minnesota, and all the western contiguous states, only six states (Arizona, Michigan, Montana, Nevada, New Mexico, and Utah) produce significant amounts of copper, and the bulk of U.S. production comes from Arizona and Utah (National Research Council 1979).

Ownership

There is little information on the quantities of minerals in public and private ownership. This is, in part, because little is known about what minerals actually exist. Further, no agency maintains statistics on the ownership of known deposits, although BLM has records for federal lands. At best, the ownership of minerals is extremely complex and often transitory; for example, minerals located on federal land become private property with the discovery of a valuable mineral deposit and the filing of necessary legal papers. The key question is not one of who owns the minerals but whether they are accessible and available for development and under what conditions.

While significant amounts of minerals are believed to lie beneath federal lands, these lands account for a relatively small proportion of domestic minerals production, which indicates that large amounts of minerals are in private ownership. For example, most of the phosphate produced in Florida comes from private lands and nearly all the iron ore produced domestically is mined on private land in Minnesota's Mesabi iron range.

There is some information on the federal government's ownership of energy minerals. In the West, the government owns about 60% of the 237 billion tons of identified coal reserves (USDI Office of Surface Mining, Reclamation and Enforcement 1987).

When the federal government acquired the national forests in the East, it often did not buy the subsurface minerals, and while some minerals rights have subsequently been purchased by the federal government, the rights to minerals beneath large areas of the eastern national forests remain in private ownership. In the late 1970s, it was estimated that private owners hold the rights to minerals under one-third of the 25 million acres of national forests in the East (Shands and Healy 1977).

Energy Minerals

According to the Department of Energy, in 1985, the United States had proven reserves (quantities deemed recoverable from known reservoirs under existing economic and operating conditions) of crude oil of 28.4 billion barrels, which amounts to about a 9 year supply at mid-1980s production rates. DOE estimates that there are about 82.6 billion barrels of undiscovered recoverable crude oil (US DOE 1987b). The United States has substantial amounts of natural gas. A 1988 study for the Department of Energy estimated that technically

Figure II-2
Map of Mineralization
Locations of Favorable to Metallic Ore Deposits

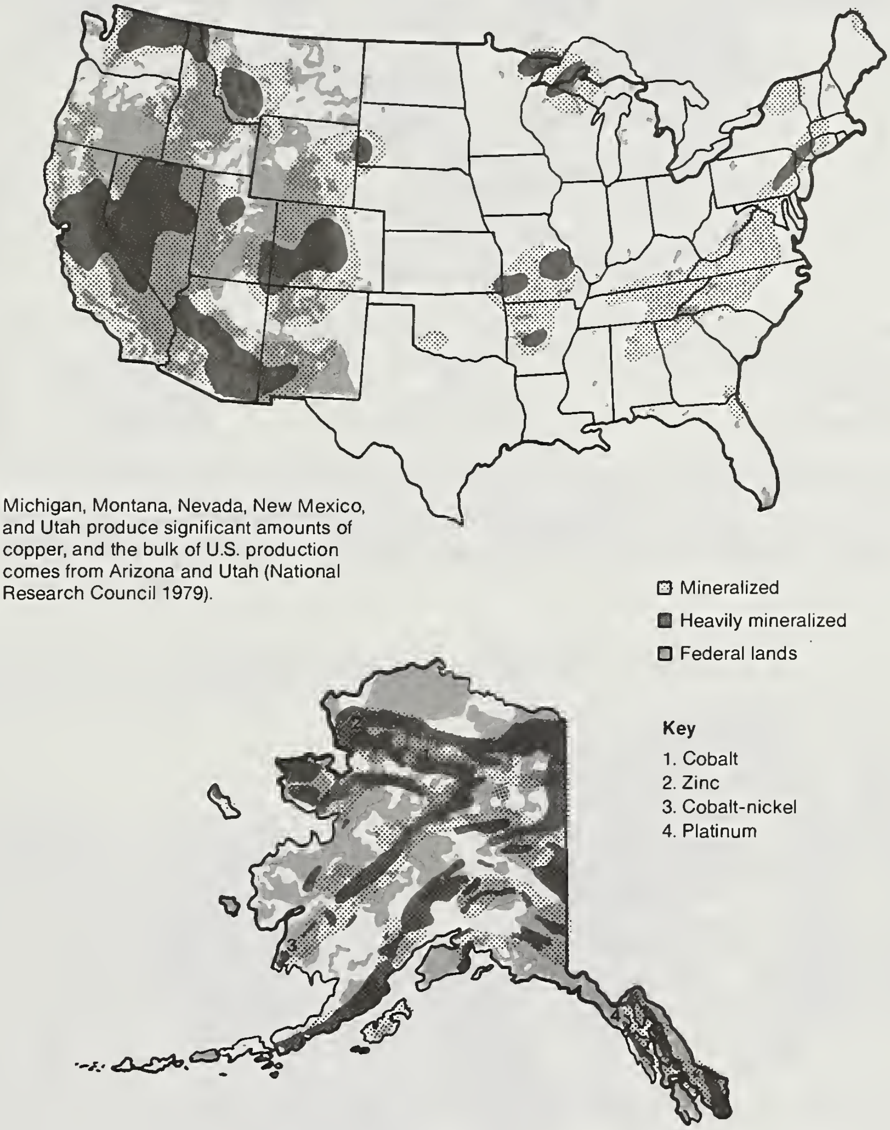

Figure 2.—Locations of favorable mettallic ore deposits.

recoverable natural gas in the U.S. reserve and resource base amounted to 1,188 trillion cubic feet (Argonne National Laboratory 1988). This figure includes 1,059 trillion cubic feet beneath the 48 contiguous states, and another 129 trillion cubic feet in Alaska. To put these amounts in perspective, as of 1984, the United States had produced a cumulative total of 130 billion barrels of crude oil and 650 trillion cubic feet of natural gas (US DOE 1985).

However, other experts contend that there are 300 billion barrels of oil that could be recovered, although it will require expensive new technology (Abelson 1987).

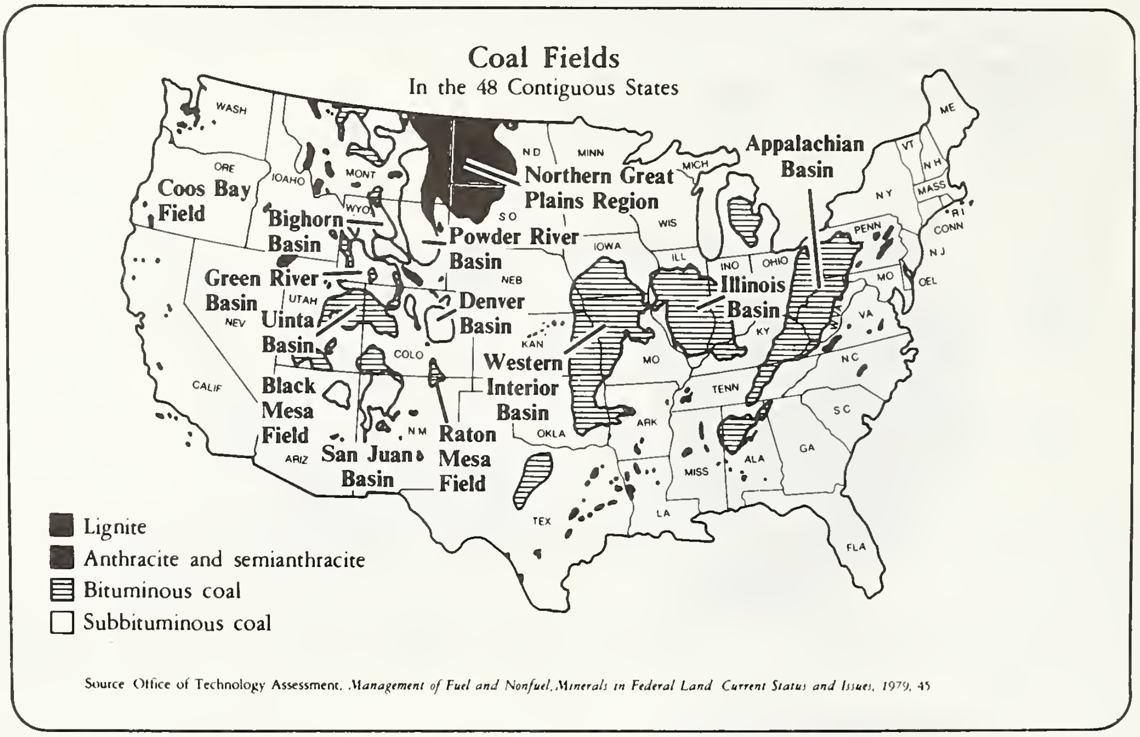

Figure 3.—Map of coal areas (U.S. Congress, Office of Technology Assessment, 1979).

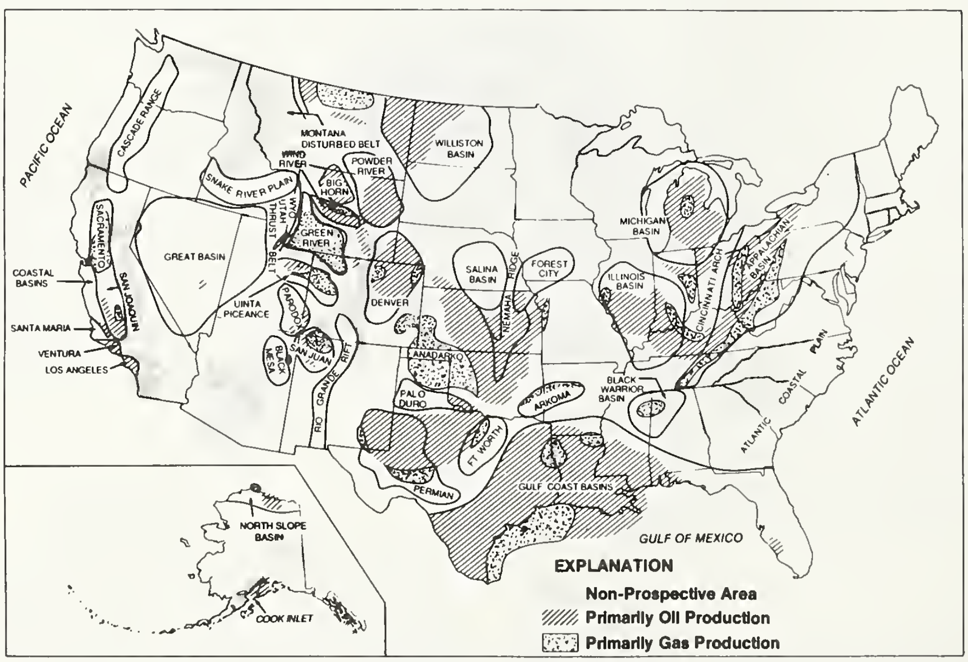

Figure 4.—Major oil and gas basins.

The potential for development of these resources is discussed in the following section on supply.

The United States has abundant supplies of coal. The nation's reserves of coal are estimated at 478.2 billion short tons (in 1985, the United States consumed 818 million short tons). There also are large reserves of oil shale with estimates ranging from the equivalent of several hundred billion barrels of oil, to more than a trillion barrels (Abelson 1987). The Nation also has large amounts of uranium, if required for nuclear power generation. There also is the potential for increased use of geothermal resources; the Department of Energy believes that

RESOURCES OF (commodity name)
(A part of reserves or any resource category may be restricted from extraction by laws or regulations (see text))
AREA: (mine, district, field, State, etc.) UNITS: (tons, barrels, ounces, etc.)

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Measured	Probability Range	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Margianl Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Figure 5.—Resources/reserves classification system.

by 1995, geothermal energy sources could provide more than double the electrical power they now generate.

Metallic Minerals

The United States has large quantities of many metallic minerals, although not all can be recovered economically at current prices or with available technology. The U.S. Geological Survey and Bureau of Mines have a system for describing the Nation's minerals resources (fig. 5) based on geologic knowledge and the economics of minerals extraction. The two major classifications are "resources" and "reserves." Resources encompass all the Nation's minerals, discovered and undiscovered. Reserves comprise minerals that have been discovered and may be either economic or marginally economic to recover, given current technology. The resource is economic if the costs of extraction and production allow the miner to profit financially from the operation.

The Bureau of Mines defines the "reserve base" as that part of the resource that might be mined given current mining and production processes. The reserve base includes all economic and marginal reserves, and a portion of the uneconomic reserves (Dorr 1987, USDI BM 1987a). The reserve base is dynamic and constantly changes because of new discoveries, new technology, and flux in local, national, and global economies. Table 14 displays the 1985 domestic reserve base estimates for the indicator minerals. The implications of these reserve base estimates for future supply are discussed in detail in the following section.

Industrial Minerals

The Nation has adequate reserves of limestone and phosphate rock (table 14), but lacks reserves of some important industrial minerals such as industrial diamonds. Mineral materials used in construction, such as sand, gravel, stone, and clay, are abundant nationwide, and widely distributed. Because of their weight and bulk, transportation is costly and typically, these materials are extracted and processed close to where they are used. While deposits typically exist near metropolitan areas, they may be rendered inaccessible by urban development, zoning regulations, and environmental restrictions (USDI BM 1985).

THE MINERALS SUPPLY SITUATION

Highlights

- While world production of oil currently is in excess of demand, increased consumption by OPEC nations and political factors could reduce the amount of foreign oil available for purchase by the U.S.
- There are abundant supplies of metallic minerals worldwide, but their cost and security of supply raise questions about their availability.
- The market for many minerals is global and complex, and for some minerals there are frequent periods of shortages or oversupply.
- A number of minerals critical to the U.S. economy or military are controlled by unstable or unfriendly governments and vulnerable to regional conflict.

- Supplies of some minerals can extend through more efficient use, conservation and recycling.

Minerals are traded in world markets to a far greater degree than other forest and rangeland resources. Domestic reserves are only one possible source of the minerals required to satisfy the Nation's needs. Thus, an assessment of minerals supplies must consider the world minerals situation. For most minerals the United States requires, there appears to be adequate worldwide supplies to anyone with the money to buy them. The question is where the United States will get the minerals to satisfy its needs and at what price.

World prices for a mineral affect the economics of exploiting domestic reserves. International politics and economics weigh heavy in industry's decisions about minerals exploration, mine development, and production. For minerals of strategic or economic importance that the United States imports in significant amounts, the critical issue is security of supplies that arises from political and economic instability of the source countries and military conflict. However, supplies can extend through more efficient use of minerals by industry, conservation by consumers, and recycling. Increased domestic production from all sources may be required during periods of military conflict.

How Prices Affect Minerals Supplies

The price of a mineral commodity is a critical variable in the supply calculus. If supplies are inadequate relative to demand, prices increase and stimulate exploration and development of mineral resources. On the other hand, a rise in prices tends to cause a decrease in consumption, either through a switch to available less expensive substitutes, conservation, or deterred use in new product or process. The words of the U.S. Department of Energy that ". . . prices play a key role in balancing domestic energy consumption, production, and [foreign] trade" (US DOE 1985) are also true for metallic minerals.

In a perfectly operating market, at some price, supply and demand reaches equilibrium—supply matches demand and some stability is achieved. In the case of some minerals, particularly abundant domestic mineral materials, the market system works well and supply and demand appear to be near equilibrium. For other minerals, the market does not work well and there are frequent periods of shortages and oversupply.

The reasons for this include the price inelasticity of most minerals and the global nature of a complex market. The decisions of individual countries or a group of nations that control a large portion of the world's supply of a mineral can reverberate worldwide. The short-term effect of decisions by OPEC on worldwide supply and prices of oil is well known. Organizations of major producing countries exist for other minerals as well. Even a single nation can have a significant effect on supplies and prices. Chile is the world's leading copper producer and its state-owned National del Cobre de Chile accounts for nearly 14% of production (Hargreaves and Fromson 1983). Thus, Chile can exert a major influence on the world copper market.

Some economically depressed countries are willing to sell their minerals at relatively low prices for foreign exchange (USDI BM 1985). This depresses world prices and discourages domestic exploration, development, and production.

The value of the dollar to other currencies also affects domestic production. A high-value dollar effectively reduces the price of foreign minerals, making them more competitive with domestic sources (USDI BM 1985).

Prices also affect the development of new technology to recover hard-to-exploit reserves, convert coal to liquid fuel, recycle, or develop substitute materials.

Energy Minerals

Supplies of oil exist in a number of free world nations in addition to the United States. The nations of the Organization of Petroleum Exporting Countries (OPEC) dominate the supply. Three-fourths of known world reserves are in OPEC countries, and two-thirds of the reserves are in five nations bordering the Persian Gulf (US DOE 1987a). The United States possesses only 4% of the known world oil reserves (Hargreaves and Fromson 1983). While there appears to be significant supplies of petroleum worldwide, the long-term picture is uncertain. Even though OPEC nations have a surplus supply, this could change. OPEC's share of world oil production is expected to rise significantly through the rest of this century; however, consumption of oil by OPEC members is expected to triple by the year 2000 and limit the amount available for export (US DOE 1987a).

Domestic supplies of oil are uncertain over the long term. It appears that most of the easily recoverable supplies of petroleum are depleted; fields in the contiguous states have been pumped for many years, causing a decline in recovery rates. The average output of domestic wells in 1984 was 14 barrels a day, compared to 801 in Mexico, 4,100 in Norway, 5,341 in the United Kingdom, and 12,011 in Saudi Arabia (Abelson 1987).

There is evidence that significant reserves of petroleum exist, but are expensive to recover and require new technology (Fisher 1987). If the price of crude oil increases, investment in these resources can become attractive. In fact, the United States continually adds technology to make oil economically recoverable, enlarges the areas of proven reserves, and makes new discoveries. The 9-year reserves-to-production ratio has held level (or increased) for more than three decades (US DOE 1987a).

Concern over potential environmental impacts has generated opposition to development of petroleum reserves on public lands, on the outer continental shelf, and in Alaska.

The outlook for supplies of natural gas is bright. According to a 1988 report prepared by the Argonne National Laboratory for DOE, of the 1,059 trillion cubic feet of natural gas recoverable in the lower 48 states, more than one-half—583 trillion cubic feet—is judged

to be economically recoverable at a wellhead cost of less than $3 (1987 dollars) per million cubic feet, including finding costs. If this is the case, the United States has, at current levels of consumption, a 35-year supply of natural gas at a cost equal to or below $3 per-million cubic feet (Argonne National Laboratory 1988). An additional 174 trillion cubic feet is economically recoverable at prices between $3 and $5 per million cubic feet.

The United States has enough coal reserves to last several hundred years. It also has significant amounts of natural gas and reserves of other fossil fuels (oil shale and tar sands) that are costly to develop but can substitute for oil. The domestic supply of uranium is sufficient to supply any foreseeable demand, with potential for increased development of geothermal resources.

Metallic Minerals

There are abundant metallic minerals resources worldwide. Considering only indicator minerals, the world reserve base is sufficient to satisfy demand at 1985 production rates for many years (table 14). The same is true of all important minerals. Although worldwide supplies of critical metallic minerals are adequate, the cost of foreign minerals and the supply security of minerals of economic and strategic importance raise questions about future availability of some minerals that the United States depends on. For example, 60% of the internationally traded copper is controlled by the nations of the Council of Copper Exporting Countries (Chile, Peru, Zambia, Zaire, Australia, Indonesia, Papua-New Guinea, and Yugoslavia). Nearly three-fourths of the world's chromite reserves are in South Africa (Hargreaves and Fromson 1982).

As previously noted, the reserve base of a mineral is constantly changing because of new discoveries, changes in the world prices, and new technology that reduces cost of exploration and extraction. Because of this flexibility in the amount of material the reserve base encompasses, long-term supply forecasts are uncertain. Supply projections are limited by their dependency on current reserve base estimates. With the exception of gold and silver, the United States has more than 16% of the world's reserve base or adequate reserves of the five metallic indicator minerals. Even in the case of gold and silver, the domestic reserve base is not insignificant. Nonetheless, the United States supplements domestic production of four of the indicator minerals (copper, lead, gold, and silver) with foreign imports. By dividing the reserve base quantities by 1986 consumption levels and assuming no new discoveries are made, it appears that the U.S. reserve base for copper, lead, gold, and silver will be exhausted in less than 50 years. Cameron (1986) compared production to reserve base for a number of minerals and concluded that ". . . the U.S. mineral position is weak with respect to a number of important minerals" and unless production (and consumption) fall or new reserves are discovered, the Nation's minerals position "will become significantly weaker through 2005."

However, reserve base estimates should be evaluated with caution, particularly when calculating long-term supply trends. Cameron's data do not mean that the Nation will run out of minerals, only that increased exploration and development is needed to maintain equilibrium between production (consumption) and supply. Supply generally increases with a rise in demand, illustrated in the case of gold. With a strong demand for gold in the mid-1980s, about 80% of all funds invested in minerals exploration in the United States focused on that precious metal (USDI BLM n.d.). More than 40 new mines opened nationally in 1986. Moreover, changes in world prices or more efficient mining and processing technologies could make current uneconomic reserves profitable to develop or stimulate exploration for new reserves. For example, by using new processing techniques, today's industry can extract copper from low-grade ores that were once uneconomical to mine.

In some cases, even deposits that are likely to remain uneconomic should count as part of the Nation's long-term supply. For example, the Bureau of Mines reports progress in recovering manganese (a vital steel alloy element the United States imports from South Africa) from several plentiful, but low-grade, domestic deposits. Although uneconomical to produce, these deposits could serve as an emergency source (Federal Emergency Management Agency 1987).

Moreover, abundant supplies of many minerals are known to exist on the seabed, but cannot be recovered economically (U.S. Department of Commerce, National Oceanic and Atmospheric Administration 1987). Because of the strategic importance of some of these minerals (especially manganese and cobalt), the Bureau of Mines is conducting research on deposits on the ocean beds controlled by the United States, as well as recovery technologies (Federal Emergency Management Agency 1987). It is possible that these offshore deposits could be economical to recover during the 50-year period covered by this assessment.

Industrial Minerals

Because of their weight and bulk, mineral materials used for construction are typically mined near where they are to be used. Thus, domestic not foreign supplies are the critical factor. Nationally, the United States has sufficient supplies of mineral materials, although there are local areas where mineral materials used in construction, such as sand and gravel and rock aggregate, do not occur or only occur in limited amounts. When local supplies are exhausted, the materials must be delivered from a distance—which is an increase in cost to the consumer. Sand and gravel is hauled by unit train from Montana to North Dakota where the material is in short supply (LaMoure 1988). In those areas where supplies of mineral materials exist, land use and environmental constraints are major factors that affect supply (USDI BM 1985).

For limestone, supply and demand is essentially in equilibrium. However, domestic consumption slightly exceeds the domestic production of the mid-1970s.

Table 15.—Recycling of non-fuel minerals as a percent of consumption, 1986.

Commodity	Units	Amount recycled	Apparent consumption	Percent
METALS				
Aluminum	1000 mton	784	5,143	15
Copper	1000 mton	479	2,136	22
Gold	mil. oz.	1.4	3.3	42
Lead	1000 mton	566	1,134	50
Molydenum	Recycled as a component of steel scrap independent of molybdenum content.			
Silver	mil. oz.	23	200	12
Tin	1000 mton	10,975	51,535	21
MATERIALS				
Limestone	"Large quantities" are regenerated by industry.			
Phosphate Rock			NONE	
Sand and Gravel	Road and concrete surfaces on a limited, though increasing basis.			

NOTE.—The meaning of the term "recycling" changes depending on commodity. Here, recycling refers to the quantity of material recovered from discarded products and old scrap not generated by current operations. This definition limits the contents of the recycling bin to material that must be substantially converted and refined through what usually are called "secondary production" processes.
Source: USDI BM 1987b, 1988.

The United States has abundant supplies of phosphate rock and produces a surplus for export.

Recycling: Another Source of Supply

The United States currently recycles a relatively small proportion of the minerals it consumes; most is lost in the waste stream (table 15). However, in the case of a few minerals, recycled material is an important domestic source. For example, there is no real domestic source of tin, yet in 1986, about 20% of the 51.5 million metric tons consumed came from recycled material (USDI, BM 1987b). Some 50% of domestic lead came from recycled material, primarily auto batteries. Recycling is affected by many of the same factors that influence development and processing of an in-ground mineral deposit, the price of reclamation relative to purchase of new supplies, degree of concentration of a mineral in waste, and available recycling technology.

The Nation's Strategic Stockpiles

The United States has stockpiles of petroleum and some critical metallic minerals to assure their availability in case of an interruption of foreign supplies. However, this is costly and contributes to the budget deficit. Moreover, when supplies are available only from foreign sources (or in the case of oil, require increased overseas purchases) acquisition contributes to the foreign trade imbalance. Thus, stockpiles are built at variable rates.

The Nation has a Strategic Petroleum Reserve goal of 750 million barrels of oil. As of December 1986, the reserve's oil inventory was 511.6 million barrels. An average of 51,430 barrels a day were added to the reserve during 1986 (US DOE 1987f). The Omnibus Budget Reconciliation Act of 1986 requires that the reserve be filled at the rate of 75,000 barrels a day. The 1987 Act did not require a specific fill rate. Instead, the fill rate is based on the 1988 budget. The Strategic Petroleum Reserve was appropriated $438.7 million dollars, of which $256.4 million is used to fill the reserve. The average daily fill rate of 50,000 barrels is based on the latter amount. The National Defense Stockpile of nonenergy minerals and some other strategic materials has excess inventory over goals in some minerals, but these are outnumbered by inventory deficits.

Security of Foreign Supplies

A number of minerals critical to the U.S. economy or military are controlled by unstable or unfriendly governments and are vulnerable to disruption by regional conflict. The assurance of supply, United States vulnerability to long- or short-term disruptions, and the timely ability to locate and develop alternative or onshore sources are of equal concern to this Nation. As discussed earlier, two-thirds of the free world's known oil reserves are held by Mid-East OPEC nations that border the Persian Gulf. In 1987 and 1988, oil tankers and port facilities were the targets in the war between Iran and Iraq. Several countries are constructing pipelines to the Red Sea and Mediterranean ports to provide oil shipping outlets less vulnerable to attack (US DOE 1987b). Nonetheless, Mid-East oil supplies remain uncertain in a region where oil is seen as a military and political weapon and a small number of countries control the bulk of the free world's supply.

Table 16. Minerals high in strategic risk*, major producing nation(s).

Mineral	Risk	Producing nation(s)	U.S. import reliance (1986)
Chromium	41.5	South Africa, Zimbabwe	75
Manganese	36.7	South Africa, Australia	100
Cobalt	35.3	Zaire, Zambia	94
Copper	28.8	Chile, Peru, Philippines, Zaire, Zambia	28
Platinum Group	28.8	South Africa, Canada	92
Gold	26.4	South Africa	46
Aluminum	23.0	Canada, Guyana, Indonesia	26
Alumina and Bauxite	NA	Australia, Guinea, Jamaica	97
Columbium	22.3	Brazil, Canada, Thailand, Nigeria	100
Tin	21.8	Brazil, Malaysia, Bolivia, Indonesia, China, Thailand, Chile	74
Diamond industrial	19.0	Botswana, Namibia, South Africa, Zaire	92

** Strategic risk index figure is based on a calculation of the likelihood of a supply disruption and its potential economic cost. An index figure over 25 is considered highrisk, 10 to 25, medium risk.*
Sources: Hargreaves and Fromson 1986; USDI BM 1987a.

A similar situation exists for some critical metallic minerals, precious metals, and minerals materials used in industrial processes. Hargreaves and Fromson (1986) developed a complex system to evaluate the vulnerability of supplies of 38 minerals of strategic importance to industrialized nations. Factors evaluated include stability of the governments of producing nations, probability of armed conflict, and vulnerability of transportation routes. Table 16 shows the minerals that ranked highest in strategic risk, the major producing countries, and 1986 United States import reliance. As the chart indicates, of the minerals ranked highest in strategic risk, in 1986 the United States imported more than three-quarters of domestic consumption of seven of them. Two of this assessment's indicator metals, copper and gold, are rated high in strategic risk. However, gold is not a strategic mineral and adequate quantities of refined material are held domestically, as are reserve assets. The others, lead, molybdenum, and silver, are either relatively abundant or available from secure sources of supply.

HOW SUPPLY COMPARES TO EXPECTED DEMANDS

Highlights

- Domestic consumption of minerals of all kinds will increase.
- The U.S. has sufficient supplies of many of the minerals it requires, although it will continue to rely on foreign sources for some minerals of economic and strategic importance.
- Where the U.S. gets the energy and metallic minerals it consumes depends to a large degree on the cost of domestic exploration and recovery versus overseas prices.
- While the demand for metallic minerals will increase moderately overall, new technologies will stimulate the demand for some minerals and reduce consumption of others.

Demand forecasts indicate that compared to today's levels of consumption, the United States will require increased supplies of minerals through the year 2040. There are ample worldwide supplies of all the minerals the United States requires. For some minerals of economic or strategic importance, the United States will rely on foreign sources and stockpiles. Most minerals, even those the United States imports in significant quantities, are or could be produced domestically in amounts sufficient to satisfy domestic demand if the cost of domestic exploration and production competes with overseas sources and the regulatory climate is favorable.

This section summarizes the information from the previous sections that describe the projected domestic demand for minerals and the U.S. and world supply situation, with a description of the likely future.

Minerals Demand: Summary and Analysis

Energy Minerals

The United States demand for energy minerals will increase. The kinds of mineral resources used to satisfy domestic demand and where they are obtained will depend on the cost of domestic minerals relative to those from foreign sources. Price also will be affected by technological advancements in minerals exploration and recovery.

The world price of oil is expected to increase during the 1990s and into the next century. This should stimulate exploration and development of domestic oil sources, utilization of oil shale and tar sands, and increased use of domestic coal and natural gas. However, the demand for coal, oil shale, and tar sands will be influenced by the development of technologies that reduce costs and environmental effects. Public concern

over acid precipitation and other environmental problems linked to coal burning could stimulate governmental action that increases the cost of coal-generated electricity to the consumer. Such concerns depress the demand for coal and stimulate the use of oil and gas, if available at reasonable prices. Geothermal resources will be developed where economically feasible. Despite past low costs, future growth of nuclear power generation and the demand for uranium will depend on measures to reduce health and safety risks. This includes the provision for disposal of high-level nuclear waste and public attitudes toward nuclear power Moreover, new technology that makes renewable, nonmineral energy cost-competitive with mineral sources could reduce the demand for energy minerals.

Metallic Minerals

In general, the domestic demand for metallic minerals will continue to increase. The Bureau of Mines forecasts growth rates averaging about 20% for selected indicator minerals through 2000. However, new technologies and products will stimulate the demand for some metallic minerals and reduce the demand for others. The forcefulness of the market is illustrated by lead; while its use as a gasoline additive is being phased out, it is now in demand to screen radiation from televisions and computer monitors (Latimer 1987). Over the 50-year planning period, demand for any given metallic mineral is likely to be highly variable.

Industrial Minerals

Demands for mineral materials used in industrial processes and construction are likely to follow trends in population growth and gross national product. Demand for fertilizer minerals could be affected by new farming techniques and overall demand for agricultural commodities that the United States produces.

The Minerals Supply Situation: Summary and Analysis

Energy Minerals

Overall, there will be no shortage of any energy minerals worldwide, although the price of oil is expected to increase significantly. The United States has ample supplies of mineral resources that could serve as alternatives to oil—natural gas, oil shale, tar sands, and uranium for nuclear power. Likewise, there are opportunities for increased use of geothermal resources to generate electricity.

Metallic Minerals

The United States has supplies of many metallic minerals sufficient to accommodate domestic demand through the assessment period. However, the United States does not have supplies of some metallic minerals of economic and strategic importance and will have to continue to depend on foreign sources. For those minerals that are present in the United States, the cost of foreign supplies vis-a-vis the cost of domestic production largely will determine the extent to which domestic demand is satisfied by domestic supplies. Restrictions on exploration, minerals production from federal land, and environmental concerns could limit domestic supplies of some minerals. For some minerals that the United States imports in significant quantities, the availability of overseas supplies will be influenced by factors unrelated to the physical existence of the resource, such as global and regional politics and the stability of the government of the producing country.

Industrial Minerals

The domestic supply of mineral materials used in construction historically has been in equilibrium with demand and no national shortage is anticipated. However, local deposits of mineral materials used in construction can deplete, and result in rising costs to consumers for transport of needed materials from distant areas.

Price/Cost and Supply Interactions

As discussed previously, the price of a mineral—or its cost in world markets—influences supply as well as demand. Higher prices stimulate domestic exploration, development, and production of a mineral—increasing supplies, but with increased costs to consumers. Similarly, rising prices serve as an incentive to increase utilization of existing reserves, more efficient use of raw materials in manufacturing, a switch to less expensive substitutes, and consumer conservation.

Other economic factors not directly related to minerals also will influence minerals consumption and demand. These include efforts to reduce the federal deficit (seen in reduction of additions to U.S. strategic stockpiles), need of foreign countries for cash, value of the dollar relative to foreign currencies, and U.S. balance of trade. Interest rates, federal and state tax policies, the price of labor, and the cost of environmental protection affect the competitive position of the domestic minerals industry. They also affect the amounts of domestic minerals consumed and demands upon domestic resources.

The Future

The ways the nation's minerals needs are satisfied—either through increasing or extending supplies—shift as the national and world economic situation changes and new technology is brought on line. This will continue. In terms of increasing the quantity of available domestic minerals, trends seem to indicate the following:

• There will be a continued reliance on foreign sources to supplement domestic supplies for both energy and metallic minerals when the price of overseas minerals is less than the cost of producing them domestically.

• Rising prices for worldwide fossil fuel energy minerals will stimulate exploration for and production of domestic energy sources. There will be an increased reliance on domestic reserves of coal.

• Domestic production of metallic minerals will rise as new exploration and recovery technologies make domestic minerals cost-competitive with foreign sources.

• There will be an increase of growing demand for industrial minerals, especially materials used in construction.

The following section considers the social, economic, and environmental implications of these trends, emphasizing increased domestic production.

SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF THE SUPPLY/DEMAND COMPARISONS

Highlights

- There is likely to be increased domestic minerals production to satisfy demand, although the U.S. will continue to import significant amounts of minerals it requires.
- The national economy will benefit from increased domestic minerals production through reduced imports and the mining industry's increased contribution to the Nation's gross national product.
- Greater domestic production will have positive and negative regional and local economic and social impacts. Positive effects will include increased jobs and higher incomes. Negative effects include the need for government investment in facilities and services; some shortages (probably short-term), in services and housing; and changes in the social and political structure, and culture of small rural communities.
- Potential environmental impacts include changes in lands and soils; esthetic degradation: and adverse impacts to water quality, and fish and wildlife habitat.

The comparison of demand and supply in the previous section indicates there is likely to be increased domestic production to satisfy demand. The United States will continue to import some minerals, either because they cost less overseas or because no economically exploitable domestic deposits have been discovered. Increased domestic minerals production will contribute to the health of the national economy; but the economic, social, and environmental effects will be most evident in communities where the mineral activity occurs or is restricted. Greater reliance on imported minerals also would have important national economic impacts and affect regions and localities.

National Effects

Encouragement of domestic minerals production would benefit the national economy in at least two ways. First, the nation's balance of trade with foreign countries will improve as U.S. industries use more domestic minerals. Imports will decline if domestic prices are favorable. If there is a production surplus, exports might increase as well. This will have a beneficial effect on the Nation's general economy and a lower reliance on potentially unstable foreign sources.

Second, the economic climate for domestic minerals industries will improve, and increase their contribution to the gross national product.

Increased minerals imports will aggravate the Nation's already serious international balance of payments deficit. The situation will be especially acute in the case of oil. While the Nation enjoyed relatively inexpensive foreign petroleum in the mid and late 1980s, experts generally agree that low foreign oil prices are not likely to last beyond 1990, and prices will rise significantly in the next century (US DOE 1985). If present import trends continue, the national bill for foreign oil could amount to $200 billion by the year 2000, about one-half of the total foreign debt in 1987 (Abelson 1987). This would place a heavy burden on the national economy.

The net import of minerals on the health of the U.S. economy, however, depends in part on the price of imports. As long as the price of foreign minerals remains low and other sectors of the economy are vigorous, the national economic effects of increased minerals imports might not be significant. Although the domestic metallic minerals industry's share of the GNP declined between 1981 and 1985, overall GNP rose (USDC BC 1986). Increased imports of relatively cheap foreign oil actually helped keep inflation in check.

Dependence on imports could have serious consequences during a time of rapid price increases. If the domestic minerals industry is unable to rapidly initiate or expand production because of United States reliance on foreign sources, the national economy could be stressed by disruptions in foreign supplies or price increases. This is similar to what happened in the case of OPEC oil in the early and mid-1970s.

The social and environmental effects of increased domestic minerals production will be widely dispersed and probably not be apparent at the national level.

Effects on Regions and Communities

Increased domestic production can be expected to have positive and negative regional and local social and economic impacts. Those impacts will be focused primarily in the areas where minerals activity occurs.

Increased onshore oil and gas production is most likely to affect parts of Alaska, the northern Rocky Mountains, and the Southwest. Increased domestic coal production will primarily affect localities in the Appalachians and coal regions of the upper Great Plains. The increase of domestic metallic minerals production

will impact primarily the West and the iron ore producing areas of the upper Great Lakes. Although larger mineral operations have greater potential for social, economic, and environmental effects, there are few large metallic minerals mines. Of 296 metallic mineral mines in the United States in 1985, only 121 produced more than 100,000 tons (USDI BM 1987a). The increase in demand for industrial minerals, especially those used in construction, will result in greater numbers of quarries throughout the country. These also tend to be relatively small operations. The vast majority of the more than 6,000 sand and gravel quarries in the United States in 1985 produced less than 100,000 tons of material a year.

Economic Impacts

Increased domestic production will have positive and negative effects in regions and localities where minerals development takes place. Positive effects include an increase in direct employment in minerals activity and higher personal incomes. The increase in employment also leads to expansion of secondary jobs and income in the retail sales and service sectors. State and local tax revenues will increase because of the increases in the direct and secondary employment. There also are likely to be short-term negative economic impacts. State and local investment will be required to pay for additional facilities such as roads, water supply, and sewers, and public services such as police and fire protection, schools, hospitals, and recreation. Short-term shortages in facilities and services can be corrected over time. Recent legislation in states such as Montana and Wyoming require minerals developers to finance some of the new social infrastructure through prepayment of taxes (Montana code annotated 75–20–101 to 1205, Wyoming Statute 35–12–101–121). Established residents may face an increase in housing costs and other goods because of an increase in demand by new residents. Other sectors of the local economy, such as agriculture, also may face higher costs for resources such as water and labor because of the demand increase stimulated by mining activity. Ultimately, there will be some financial stress when depletion or market changes lead to closure of the minerals development.

A number of factors affect the balance of adverse and beneficial economic effects: size of the mine and value of the mineral mined; number of workers employed and skills required; development pace; and duration of activity (Wenner 1984). The policies of the developing company to hire local people and buy in the local economy can affect the economy of the community. Large mining companies make deliberate efforts to maximize the local economy and establish cooperative relationships that address local concerns (ASARCO 1982).

The characteristics of a local community that affect its ability to accommodate economic growth are size, degree of isolation; government's and business sector's ability to cope with growth; opportunities for advanced planning, labor supply; and whether the economy is diversified, single-sector, stable, or depressed.

In some cases, increased national reliance on foreign sources of minerals will cause domestic mines to close, which results in losses of jobs and depression of regional or local economies where minerals production is a major element. For other communities, the loss of a domestic minerals market to overseas sources means a loss in economic growth and diversification through development of local minerals resources.

Whether the decline of a local mine or its closure results in a net loss to the community depends largely on the availability of other economic opportunities in that community. Other sectors of the economy may expand and compensate for lost minerals activity. Some port cities will realize economic benefits from increased minerals imports. Consumers also can benefit from imports if those imports prices are lower than domestic sources.

In summary, the national economy can expect to improve as a result of increased production of domestic sources. Regional and local economies will benefit from employment and income increases, but may feel pressure to provide facilities and services for greater numbers of workers and their families. Increased imports, on the other hand, will contribute to problems at the national level. This includes increases in the Nation's international trade deficit, although consumers may benefit from cheaper imported goods. Increased imports can cause negative impacts on local communities if domestic mines close because they are not cost-competitive with foreign supplies.

Social Impacts

As in the case of economic impacts, the development of domestic mineral resources can be expected to generate positive and negative social effects. Increased economic activity and employment can generate feelings of social well-being. New jobs also will make it possible for young people to remain in the locality. New employment opportunities may attract an influx of workers and their families and change the social and political structure, and culture of small rural communities (USDA FS 1980). This influx may lead to friction between newcomers and established residents, especially if they differ in culture, education, and economic status. An increasing population requires more schools, increased health care systems, law enforcement, and social services. A larger population will stimulate long-term improvement in social services, medical facilities, schools, and cultural and entertainment opportunities.

Some communities are more capable than others to assimilate new people and meet housing and social services demands. A community's ability to cope with social disruption depends on many of the same factors that affect its ability to deal with economic change. Generally, communities that suffer employment and income losses also will have difficulty adjusting to the social demands of large-scale minerals development.

The regional and local effects of increased imports of foreign minerals at the expense of domestic production

also will be mixed. If foreign imports result in the closure of domestic mines, many individuals will lose their jobs. These individuals would have to move to other areas, take less desirable jobs in the same locality, or possibly accept short-term public welfare.

In summary, the social effects of increased domestic production are felt mainly at the regional and local levels. Social benefits relate to long-term job increases, higher incomes, and improved social services and cultural and educational opportunities. However, there are likely to be short–term adverse effects because of cost increases to local governments, social changes that accompany rapid, and unplanned growth, and changes in the character of local communities.

Environmental Impacts

Increased domestic minerals production has potential for adverse environmental impacts in the areas where minerals development occurs.

The increased use of foreign minerals results in less environmental concern in this country. The direct environmental effects of the minerals development is transferred overseas to developing countries where environmental standards are far less stringent than in the United States.

The nature and severity of potential environmental impacts depend on a number of factors. Among them are the ecological character of the land developed; the mineral mined; methods to extract and concentrate the ore; the use of available technology to mitigate adverse impacts; policies of the mining company; and the enforcement of mitigating measures by local, state, and federal entities. Many laws and regulations address the environmental impacts of mining. Enforcement at all levels could effectively mitigate many of the significant effects experienced in the past.

Some environmental effects are site specific, such as storage of mine tailings. Others have broader regional effects, such as water pollution.

Environmental effects also vary in duration. Some effects are greatest when the mine is active. Changes in the landscape and toxicity of mine waste can persist long after mine operations cease. Often post-mining impacts, particularly water pollution, are the most difficult to mitigate (National Research Council [NRC] 1979, U.S. Environmental Protection Agency [US EPA] 1985).

The U.S. Environmental Protection Agency (1987) studied 31 "environmental problems" that included mining waste. Mining waste was rated in four categories of environmental risks and found low in non-career health risks and welfare effects, moderate in cancer risk, and high in ecological risk.

While some short-term environmental degradation may be inevitable, there are measures that can be taken to avoid or mitigate most of the adverse environmental effects (PEER Consultants 1984, US EPA 1985). Enforcement of federal, state, and local environmental quality laws will prevent some of the most serious adverse environmental effects. For example, the Surface Mine Control and Reclamation Act (SMCRA) provides for federal incentives to states to regulate surface coal mine operations and ensure adequate reclamation. Congress exempted mining from coverage under the Resources Conservation and Recovery Act (RCRA) pending a study by the U.S. Environmental Protection Agency of the hazards of mining waste (US EPA 1985). Subsequently, EPA has studied the concern and found that mining wastes do not require management as do hazardous wastes under Subtitle C of RCRA. A regulatory program (Subtitle D of RCRA) is under development. Some localities have zoning laws and regulations that minimize conflict between minerals development and other land uses. There is evidence that the mining industry has responded to public pressure and federal legislation of the 1970s with improved techniques that reduce environmental effects, such as the reclamation of mined lands (Cameron 1986).

Increased domestic minerals production will have various environmental effects on land use, soils, esthetics, water quality and quantity, wildlife, and potentially human health in localized areas. The most significant effects are summarized below.

Increased domestic minerals development will lead to land disturbance that will temporarily remove some areas from timber production, range forage, wildlife habitat, and recreation uses. However, the amount of land in the nation actively used for mining is relatively small. In 1980, the last year figures were available, 228,000 acres of land were actually used for mining nationwide (Johnson and Paone 1982). From 1930 through 1980, only one-fourth of 1% of the U.S. land was utilized for mineral extraction. A 1984 study on coal surface mining estimated 73,000 acres were "newly disturbed" nationwide, and the total disturbed area amounted to 146,000 acres (PEER Consultants 1984). The commitment of land is not large when compared to the Nation's total surface, even in areas where mining activity is or has been prevalent. For example, Kentucky, Pennsylvania, and West Virginia only have about 2% of their total land area disturbed; Illinois, Indiana, and Ohio have had about 1% (Johnson and Paone 1982). Phosphate mining in central Florida affected 166,000 acres, or only 3.2% of the land in a seven-county area, compared to 9% for urban development (NRC 1979).

Mine sites can be reclaimed for beneficial uses, such as open space, fishing lakes, and wildlife habitat. In the mountainous areas of the East, level sites can be used for playfields and housing (NRC 1984, Stearns 1985). The ease and effectiveness of reclamation depends on topography, the nature of the soil, waste material, and rainfall (National Academy of Sciences 1974, US EPA 1985). In contrast to the past, there are expected to be fewer waste dumps and tailings that resist revegetation and are left unsuitable for human use or wildlife habitat.

Minerals development can affect the long-term land and soil condition. Soil compaction changes soil physiology. Soil chemistry can be altered by the introduction of toxics, both of which yield soil conditions that make revegetation difficult. It was estimated that 1.3 billion metric tons of waste would be generated

by mining extraction and processing in 1985 (US EPA 1985). Of this, 361 million tons would be toxic or acidic to some degree, making reclamation difficult and costly.

Increased underground mining increases the potential for subsidence, while disposal of waste on steep slopes increases the potential for erosion and slumping (PEER Consultants 1984). Increased phosphate mining in some areas will result in greater amounts of mine slimes (waste clays deposited as a slurry) that take decades to stabilize (NRC 1979).

Mineral development, especially waste piles that have not been reclaimed, adversely affect scenic quality. For example, coal mining in Appalachia and metallic minerals development in the West adversely affect scenic quality near the mine site. Coal mine highwalls are seen from highways in the mountains of Kentucky, West Virginia, and Virginia. Copper mine waste piles are seen from the highway through scenic mountains east of Phoenix, Arizona. The visual impact is greatest from surface mining. Surface mining accounts for 95% of metallic minerals and minerals materials extracted in the United States and 99% of mine waste (NRC 1979).

Increased minerals development increases the chance of surface and underground water pollution. This pollution is in the form of drainage, seepage, and runoff from the mine site, waste dumps, and tailings. Depending on the mineral and method of concentrating, the ore runoff may contain toxics. The disposal and treatment of water laden with chemicals is a technological challenge. There also is a risk of accidental discharge of waste through failure of retention dams and pipes (NRC 1979). A recent study found that "only a small percentage of [metallic minerals] mines currently monitor groundwater, use run-on/runoff controls or liners, or employ leachate collection, detection, and removal systems" (US EPA 1985).

Water quality also can be a problem after mine operations cease. Subsurface contamination is a difficult problem with abandoned deep mines (NRC 1979).

Mining also affects the quantity of water in some areas. For example, phosphate mining in Florida lowered the water table 40 feet at some sites, which resulted in the loss of some wetlands and disruption of water flows (NRC 1979). Diversion of water for mining in the West can have an adverse effect on riparian systems.

Although mining operations are regulated to mitigate adverse effects on fish and wildlife, there will be effects on some wildlife and fish because of habitat alteration. Wetlands, riparian systems, and deserts are especially vulnerable. Some wildlife species will be disturbed by the activity associated with mineral development. For example, there is special concern about the potential effects of mining on the grizzly bear population in the northern Rocky Mountains (Matthews et al. 1985). Mining could decrease instream flows in some areas and affect fish and wildlife dependent on riparian habitats and wetlands. When properly reclaimed, some mining sites can contribute improved fish habitat and recreation opportunities. Coal mine pits in the East, for example, may be transformed into fishing lakes, and provide new habitat and recreation opportunities (Stearns 1985).

Local, state, and federal regulators are building mitigation measures into the mining plans over which they have jurisdiction. These efforts, and approved mining operations minimize the impacts on wildlife, fish activities, and habitats.

Local air quality problems can include wind-blown dispersion of radioactive radon gas from uranium mine ore piles, mill tailings, waste dumps, and toxic metals from some other kinds of operations (NRC 1979). There will be some increased hazard to human health from mining. This will result from an inadvertent release of toxics and radioactivity into surface and underground water, wind dispersion and radioactive radon gas, and heavy metals from mine sites (US EPA 1985).

In summary, environmental effects from increased domestic minerals production will occur primarily at the regional and local levels. While there are risks of significant effect in some regions and localities, industry compliance and law or regulation enforcement will reduce these risks.

OPPORTUNITIES FOR MEETING THE NATION'S MINERALS NEEDS

Highlights

- Domestic minerals needs can be satisfied by increased domestic production and imports, extended supplies and materials substitution.
- Opportunities for increased domestic exploration production can be enhanced by improving the business climate, encouraging minerals production on private lands, facilitating minerals development on federal lands, and by improving information on domestic minerals location, quantity and quality.
- Opportunities to increase imports can be improved by tax and trade measures and bi-lateral agreements with foreign nations.
- Supplies can be extended through more efficient recovery in mining and processing, more efficient use in manufacturing and consumption, and recycling.
- There also are opportunities to substitute nonmineral materials, abundant minerals and technology for scarce minerals.

Several numerous opportunities may be available to accommodate the projected increase in the Nation's demands for minerals of all kinds over the next 50 years. They include increasing domestic exploration and production, increasing imports, extending supplies through efficiencies in the extraction and use of minerals and recycling, and substituting abundant minerals and renewable materials or technology for scarce minerals.

Oil imports supplement domestic supplies and the manganese is imported because no economic domestic deposits have been discovered. Molybdenum and construction materials are mined domestically in sufficient amounts to satisfy demand. Large amounts of lead are recycled and per capita consumption of energy has declined through more fuel-efficient autos. Optical fibers (a new technology) are replacing copper in communications.

Increasing Domestic Supplies

Market forces and access largely determine whether industry will explore and develop domestic supplies or import minerals from overseas to satisfy United States demand. The role of government to stimulate domestic production is limited, yet an array of government policies (on taxes, foreign trade, environmental protection, and use of the public lands) influence industry decisions. Governments can provide financial incentives to encourage industry to exploit domestic sources but such measures need to be weighed against social, economic, and environmental objectives.

Improving Business Climate

If domestic minerals are to provide for the Nation's growing demand, industry must be able to explore, develop, and sell its products at a competitive price with overseas sources. The challenge for industry is to make exploration, extraction, and processing more cost-efficient to offset rising costs (Latimer 1987). Industry has made strides toward reduction of production costs and progress in this area will have to come from industry. However, governments might review tax, trade, and environmental policies to see if they unnecessarily inhibit development of domestic minerals resources and constrain the marketplace. Domestic production can be stimulated by tax incentives and low interest loans, as done in the 1950s and 1960s (McDivitt and Manners 1977).

Increasing Mineral Production on Private Land

Decisions on exploration and development of minerals on private land rest with the mining company and the landowner. However, the U.S. Geological Survey can facilitate exploitation of minerals on private lands by increased efforts to identify potentially economic deposits of minerals. The U.S. Geological Survey has a geologic map of 17 eastern states that shows the location of more than 2,200 known deposits of metallic minerals. This includes a number of strategic minerals that the United States imports (Federal Emergency Management Agency 1987).

Mineral materials used in construction, such as sand, gravel, and crushed rock, are expensive to transport and usually mined close to where they are used. In many areas of high population growth, mineral materials vital to construction are in short supply and threatened by urban development. There are opportunities for state and local governments to use their land use planning and regulatory authority to divert development from areas with minerals deposits, especially deposits of mineral materials used in expanded urban construction. For example, California state legislation encourages local jurisdictions to protect high quality deposits of statewide or regional significance (Beeby 1988).

Increasing Mineral Production on Federal Land

Significant supplies of energy, metallic, and some industrial minerals underlie federal forests and rangelands, which include lands in the National Forest System. Key factors are access to the minerals and time required to obtain the necessary approvals and permits. While industry understandably is concerned about constraints on access to minerals beneath federal lands, these lands must satisfy a number of public needs and desires. Congress and land management agencies foreclose or restrict minerals exploration and development in some areas because nonmineral values are higher than the value of the mineral resources. It also is felt that minerals can not be extracted without impairing other values over the long term. For industry, time is money. Timely processing of applications for minerals activity can facilitate exploration and development on lands open to minerals exploration and development. The incentive to invest in domestic exploration and production also can be enhanced by removing some of the insecurity of rights to locatable minerals on public lands (U.S. Congress, Office of Technology Assessment 1979).

Improving Information on Domestic Minerals Resources

Greater efforts to identify areas of high mineralization, with assessment of quantity and quality of promising deposits, will have multiple benefits. Improved information on the quantity, quality, and location of domestic minerals resources, will increase the cost-effectiveness of exploration and development.

Improved information on mineral resources will facilitate advanced planning for development and result in more efficient investment of money and manpower. Advanced planning also might reduce or prevent adverse environmental, social, and economic impacts that generate opposition to some development proposals. Moreover, the identification of specific areas of high potential on public lands might discourage the tendency toward large scale withdrawals of land from mineral exploration and development. Improved mapping on private lands of known deposits or high potential areas can encourage development.

A better base of information might help identify domestic reserves of minerals that are exclusively or substantially imported. The United States probably possesses reserves of important minerals that it now imports from foreign sources. For example, the nation's first platinum and palladium mine opened on national forest lands in Montana in 1987 and decreased U.S. reliance on South Africa for these strategic minerals (Sheppard 1987).

Increasing Research and Development of Technology

New technology will help reduce the cost of exploration and extraction, make domestic minerals more competitive with foreign sources, and make some

uneconomic resources economic. This is particularly true of offshore resources and minerals in seabed crusts that cannot be economically recovered. The Bureau of Mines and U.S. Geological Survey test dredge equipment that will permit sampling of these crust deposits. The Bureau of Mines also is working on technology that will permit recovery of manganese from low-grade domestic resources in case of a supply disruption (Federal Emergency Management Agency 1987). Research also can explore ways to reduce or mitigate adverse impacts to surface resources and the environment and improve reclamation of mined lands. Perhaps this will lessen the opposition to mining as a land use.

Ensuring Emergency Supplies of Critical Minerals

For critical minerals not available domestically or in short supply, domestic needs in time of disruption can be satisfied over the short term by an increase in minerals stockpiles of economic and strategic importance. Further, exploration for domestic supplies can be intensified to find economic and uneconomic sources that can be used in an emergency.

Increasing Imports

For some minerals, such as oil, natural gas, and a number of metallic minerals, the Nation's rising demand can be met by increased imports from foreign countries. While supplies of oil and gas from the Middle East are uncertain, there are secure overseas sources of supply for most metallic minerals. International minerals markets and industry's efforts to reduce domestic production costs will determine the extent that the United States satisfies its demands by increased domestic supplies or imports of foreign minerals. However, the United States will continue to rely on overseas sources for some metallic minerals either because they are cheaper or there are no economic United States deposits. The United States can facilitate overseas imports to satisfy demand through tax and trade measures that encourage United States firms to invest in overseas mines. Trade policies and binational agreements assure stable supplies from countries where the probability of disruption through government policies or regional conflict is low.

Extending Supplies

There are a number of cost-saving opportunities to extend supplies. These include more efficient recovery of minerals and utilization of low-grade ores, more efficient use by manufacturers and consumers, and recycling.

The development and application of technologies that permit greater efficiencies in extraction and processing of raw minerals, with a larger portion of recovered mineral and less waste, is one way to extend supplies. Greater efficiencies in manufacturing, which use less minerals and minimize waste, is another. Consumers can contribute to the extension of supplies by using more efficient products, such as fuel-efficient automobiles and energy-efficient appliances.

Small amounts of minerals that Americans consume are recycled, although the quantity seems to be increasing. Discarded minerals are another possible supply that could extend supplies of raw minerals.

Substituting Nonmineral Materials

The substitution of nonmineral materials, which includes renewable resources, can extend supplies of some minerals. Their special or unique attributes reserve their use. New materials, that combine nonmineral substances with minerals are being developed (Sousa 1987). Thus, composite materials that combine ceramics and polymers with metals are replacing the traditional commodity metals such as aluminum, copper, and carbon steel. Solar energy can be substituted for energy minerals in some applications, and wood substituted in many uses for steel, aluminum, concrete, and plastics. Substitution of renewable resources results in less energy consumed in manufacturing and less pollution.

Greater use of these strategies for extending supplies and substitution will occur if the price of minerals rise. However, use efficiencies and recycling can be facilitated through economic incentives, much as the tax credit for solar collectors stimulated consumer investment in solar as a renewable energy source in the 1970s. Increased research and conservation development, recycling, and renewable resource technologies can reduce costs and environmental risk.

CONSTRAINTS TO IDENTIFIED OPPORTUNITIES

Highlights

- Profitability uncertainty deters investment in minerals exploration and development.
- Information on the Nation's minerals resources is poor.
- There are perceived conflicts between minerals development and other social, economic and environmental objectives.
- Laws, policies, and staff shortages inhibit development of minerals on federal lands.
- Cost and perceived inconvenience discourage efficient use, consumer conservation, and recycling to extend supplies.

There are a number of constraints with the opportunities identified in the previous section. These include marketplace uncertainties, lack of information about the location and quality of domestic minerals resources, uncertainty of foreign supplies of some minerals, and lack of technology for exploration, development, and increased efficiency of use. While significant, most can be overcome.

Investment Uncertainty and Risk

Uncertainties of the marketplace, including price and demand, deter industry investment in domestic resources. There is considerable economic risk in minerals exploration and development. Large amounts of capital are required to find economically developable deposits and open a new mine. Moreover, price and demand can change significantly during the lengthy period between exploration and production. Thus, uncertainty over the potential profitability of a mine can discourage investment in domestic minerals exploration and development.

Volatile world prices contribute to this uncertainty. World prices of most metallic minerals fluctuate widely. While not as volatile as metallic minerals, the price of oil soared in the 1970s, and fell in the 1980s as OPEC nations reduced prices and increased some exports. Market instability is contributed by foreign governments that directly intervene in supply and price decisions. Low prices of foreign minerals and oversupply of some minerals inhibit domestic production, although consumers benefit from cheap overseas supplies. The instability of minerals markets is a significant obstacle to domestic minerals production because of the high cost to find an economic mineral deposit, obtain required government approvals, and the time and cost to develop a mine.

Comparative Costs

Domestic minerals generally cost more to produce because remaining deposits are more costly to find and develop, labor costs are higher in the United States than overseas, and the environmental protection standards are higher. On the other hand, U.S. industry attracts investment because of this Nation's stable government and economy and high quality workforce. As noted earlier, industry has made significant strides to restructure operations and utilize more efficient technology to reduce costs and make domestic supplies more competitive with overseas sources.

Inadequate Information

Insufficient information on the location, quantity, and quality of the Nation's minerals resources are another obstacle in the realization of the Nation's minerals potential. Much of the Nation has not been examined for minerals potential using modern geological and geophysical exploration techniques. About one-half of the Nation is geologically mapped in sufficient detail to provide a sound base for minerals exploration (Cameron 1986).

Development Opposition

There is considerable opposition to minerals development, especially on federal lands. This stems from perceived conflicts with surface land uses, concerns over broader environmental impacts, and state and local concerns that development will impose social and economic stress in possible mining areas. This results in large-scale withdrawals of federal lands from minerals development, and state and local land use controls that restrict minerals activity (American Mining Congress 1987).

Inadequate Management of Minerals on Federal Lands

Laws, policies, and insufficient staff contribute to inefficiencies in the development of mineral resources on federal lands and lost opportunities. Neither industry nor environmentalists appear to be satisfied with the current situation. Areas of adequacy that are challenged today include:

- Low cost minerals available on federal lands which tends to discourage exploration on private land;
- Laws that protect surface resources and the practice to withdraw large land areas (congressionally or administratively);
- Management of minerals on federal lands should be anticipatory, rather than reactive;
- Staff, such as minerals geologists and other specialists, need to plan for minerals development, analyze proposals, and administer minerals operations; and
- Consideration of minerals in federal land and resource management planning.

The statutory framework for minerals exploration contributes to differences in planning for minerals and planning for other resources. One analyst asserts that "for the most part, Congress has chosen to perpetuate an industry and market-oriented regime operating alongside, and many times outside, the renewable resources planning system" (Berck and Dale 1984).

Uncertainty of possession and tenure on public lands also may act to deter exploration and development of minerals. In its 1979 report on the management of minerals on federal land, the Office of Technology Assessment (OTA) concluded that "tenure for minerals activities is uncertain and insecure ... there is no way to obtain exploration rights secure against the government even after particular targets have been staked" (U.S. Congress, OTA 1979). Moreover, OTA found that the laws that exist offer "weak protection against other mineral explorers."

National Minerals Policy

On numerous occasions, Congress has asserted an interest in encouraging and facilitating development of the Nation's minerals resources (American Mining Congress 1987). In 1980, Congress passed the National Material and Minerals Policy, Research, and Development Act. This Act declares that it is the policy of the United States to promote an adequate and stable supply of materials necessary to maintain national security, economic well–being, and industrial production. Appropriate attention should be given to a long-term balance between resource production, energy use, healthy

environment, natural resources conservation, and social needs. However, there remains no definitive policy that describes goals or priorities for the production of domestic minerals. Minerals management is still fragmented among several federal agencies, and coordination is poor (American Mining Congress 1987, U.S. Congress, OTA 1979).

Constraints to Increasing Imports

Major obstacles stem from pressures on the Nation's economy to satisfy the Nation's minerals needs through increased imports. The Nation's balance of payments deficit generates a national interest in domestic materials and products use whenever possible.

In addition, the supplies of some overseas minerals are uncertain because of regional conflict, unstable governments, and the supply and pricing policies of producing nations. Despite the obstacles, there remains a need to develop assured supplies of minerals of economic or strategic importance that are not available domestically or are scarce.

Constraints To Efficiencies in Mining, Use, and Recycling

Major obstacles to increased efficiency in mining, use, and recycling arise from a lack of technology. Technology enables industry to recover a greater proportion of minerals from deposits, and economic and environmentally-sound methods to recover a greater proportion of the base metal from ore. The major obstacle for increased efficiency in the use of metals in manufacturing is cost. As long as supplies of minerals are cheap, there is no incentive to reduce their use in manufactured products or waste. A similar situation exists with consumer efficiency. As long as goods (and energy required to operate them) are inexpensive, there is no reason to conserve. The initial high cost of conversion technology and conservation devices discourages the use of energy conservation equipment. Convenience also obstructs the ability to extend supplies. Disposable items made from minerals are favored for their convenience. Convenience also is a factor inhibiting recycling. Some consumers resist efforts to prepare materials for collection for recycling. Recycling is constrained by lack of technologies for cost-effective collection and processing.

Constraints to Use of Substitutes

Major obstacles to the use of substitutes for some minerals have to do with their suitability for the job—such as weight and durability. Relative cost, in per-unit cost of a product and expense of long-term operation and maintenance, also is a factor. While new, high-technology materials are substituted for traditional commodity metals in many uses, there are no adequate cost-competitive substitutes for minerals for other applications. The use of solar energy, for example, is limited by climatic and cost factors. Wood requires more long-term maintenance than aluminum.

IMPLICATIONS FOR RENEWABLE RESOURCE PROGRAMS

Highlights

- There are opportunities to increase production of minerals beneath the Nation's forests and rangelands, but measures have to be taken to ensure environmental quality is maintained.
- While private lands provide many opportunities for minerals development, there will be increased production on federal lands, including the National Forest System.
- The Forest Service will have to be able to accommodate increased interest in minerals of all kinds on the National Forest System lands.
- This will require improved agency minerals management capability; integration of minerals into planning for all forest resources; review of laws, policies, and regulations; and increased research on ways to develop minerals with minimum impact on surface resources and values.

An increased demand for minerals has significant implications for management of the Nation's forests and rangelands. There are opportunities to increase domestic production of minerals that lie beneath these lands, but increased management is required to ensure that minerals development is compatible with other uses and environmental quality is maintained.

Major opportunities exist to increase minerals production from private forests and rangelands. A large proportion of current minerals production occurs on private land, and there is evidence that major deposits lie beneath private lands in the eastern part of the country. Generally, private land is easier to access. While general environmental quality must be maintained, restrictions on minerals development are not as rigorous as on federal lands where the long-term productivity of other resources are a major consideration.

Increased development of minerals on private lands has major implications for federal agencies. The U.S. Geological Survey provides information on the location, quantity, and quality of the Nation's minerals resources. The Office of Surface Mine Reclamation and Enforcement is responsible for administration of the Surface Mining, Control, and Reclamation Act. State and local agencies regulate specific land uses.

Even if private lands provide the bulk of domestic minerals, there is likely to be increased minerals exploration and extraction on federal lands, including the 191-million acre National Forest System. The national forests and grasslands generally are located in major belts of mineralization, both in the West and East. With some notable exceptions, the national forests now supply a small portion of the minerals produced domestically (table 17) (USDA FS, Minerals and Geology

Table 17. Estimated production of selected minerals on national forest land for 1986 compared to total national production.

Commodity	Units	Forest service production	Total domestic production	% production on NFS lands
Crude Oil	M barrels	18,917	3,168,252	.60
Natural Gas	MM cu ft.	189,663	15,991,000	1.19
Coal	Mston	41,221	890,315	4.63
Uranium	MM lbs.	1.50	13.20	11.36
Geothermal	Kilowatts	17,677	1,580,000	1.1
Lead	metric tons	223,455	353,115	63.28
Phosphate	M metric tons	1,814	38,700	4.69
Copper	metric tons	93,995	1,479,432	6.35
Molybdenum	M lbs.	65,275	93,976	69.46
Gold	M troy oz.	564	3,733	15.10
Silver	MM troy oz.	4,456	34,200	13.03
Sand & Gravel	MM stons	13	883	1.5

Source: USDI BM 1986, USDA FS 1988.

Management Staff 1988). However, the national forests contribute significantly to the Nation's production of molybdenum (69.5% of national production), gold (15.1%), lead (63.3%), silver (13.0%), copper (6.4%), and phosphate (4.7%). In terms of energy minerals, the national forests produced 11.4% of the nation's output of uranium in 1986, only 4.6% of coal, 1.2% of natural gas, and .6% of oil produced domestically. Production, however, is not an accurate indicator of mineral potential because access to federal lands for minerals development typically is more difficult than for private lands, and tenure less certain.

It is known that 6.5 million acres of the National Forest System is underlain with coal, 45 million acres have oil and gas potential, and 300 acres have oil shale potential. Another 300,000 acres have known phosphate potential (USDA FS 1985). *Geologically, the national forests contain some of the most favorable host rocks for mineral deposits.*

With increased demand and favorable markets, interest in minerals underlying the national forests is expected to intensify. For energy minerals, rising prices are likely to result in increased exploration for and development of, oil, gas, coal, and geothermal resources, though uranium activity is questionable. Activity for metallic minerals will continue to be opportunistic and depend on demand and world prices. Development of industrial minerals, such as limestone and phosphate rock, also is likely to increase at a moderate pace. Where construction minerals (crushed rock, sand, and gravel) exist on national forests near expanding population centers, demand for those minerals will intensify. There also is likely to be a growing demand for crushed rock, sand, and gravel from national forests in rural areas for the construction and reconstruction of roads and highways.

In summary, the Forest Service will have to accommodate an increased interest in minerals of all kinds on National Forest System lands. It also will be asked to respond quickly to metallic minerals industry proposals, given the volatility of world markets. The challenge for the Forest Service is to make minerals available from the National Forest System and not compromise other uses and values.

The Forest Service's minerals mission is to "encourage, facilitate, and administer the orderly exploration, development, and production of minerals and energy resources on National Forest System lands to help meet the present and future needs of the nation" (USDA 1986b). Minerals activity should be conducted in an environmentally sound manner, integrated with the planning and management of other national forest resources, and ensure that disturbed lands are reclaimed for other productive uses.

However, the Forest Service cannot create minerals the way it can grow trees. It can affect supply only indirectly by providing access to minerals that underlie National Forest System lands. Its authority varies according to the statutory class of minerals.

The Forest Service has discretion to manage mineral materials (such as sand, gravel, and rock for crushing) as it sees fit. It can sell them, use them for Forest Service projects, provide them free of charge to state and local governments, or not dispose of them at all.

Leasable minerals (fossil fuel minerals in the West, and minerals on acquired land except for common varieties) are made available through decisions to lease made by the Secretary of Interior. Developers can apply for a lease for some areas where they believe minerals exist. The Federal Onshore Oil and Gas Leasing Reform Act of 1987 gave the Secretary of Agriculture (and by delegation, the Forest Service) increased authority to regulate leasing on National Forest System lands. Previously, the Forest Service had only an advisory role, with primary leasing responsibility resting with the U.S. Department of Interior's Bureau of Land Management. The new law provides that the Secretary of Interior cannot issue a lease over the objections of the Secretary of Agriculture and that the Forest Service approve and regulate all surface-disturbing activity that may occur on a lease.

In the case of locatable minerals (generally, metallic minerals beneath public domain in the West), the

Mining Law of 1872 grants miners free access to these minerals. However, later authority gives the Forest Service some control over their development. Control is through construction of roads, effective planning, increased efficiency in processing operating plans, and enforcement of environmental laws and regulations in ways that reduce public opposition and time-consuming appeals and lawsuits.

Improved Minerals Management Capability

Conflicts between minerals extraction and national forest surface resources and uses can be reduced through improved minerals management. With increased minerals activity, more technical personnel are needed to plan for minerals development, participate in interdisciplinary planning teams, review development proposals and prepare environmental and social impact assessments, and monitor minerals exploration, development, and reclamation. The Forest Service currently processes 25,000 minerals cases annually, yet the Forest Service has only 96 minerals geologists and mining engineers (LaMoure 1988).

A resurgence of gold mining activity in the West, and the advent of new processing techniques using toxics to leach the metal from ores, require design and monitoring to ensure that environmental risks are minimized. There also is a need to continue to train personnel with overall responsibility for managing national forests in minerals management to integrate use of minerals resources with management of surface resources, uses, and values.

Integrating Minerals into Land and Resources Planning

The prospect for increased minerals development on National Forest System lands requires improved planning for minerals exploration and development and integration into planning for all the national forests' resources and uses. In 1987, the Bureau of Mines, the U.S. Geological Survey, and the Forest Service entered into an interagency agreement setting policy to conduct mineral resource surveys on National Forest System lands to provide information to develop forest plans.

While it occurs, minerals development displaces some uses of the national forest surface, and requires that choices be made in the allocation of resources. Thus there is the need for information about the value of the mineral resource, surface resources and uses so that comparative values and tradeoffs can be evaluated by the Forest Service and the public. To ensure that these values are adequately considered, and future options not arbitrarily foreclosed, minerals development should be integrated into national forest land and resources management plans. Integrated planning should minimize impacts to surface resources and uses and environmental risks. With careful planning, uses of surface resources can take place as mined land is reclaimed.

Improvements in the Legal and Administrative Framework

Improvements in the legal and administrative framework for minerals management will be required. These include a review of regulations to ensure they are adequate; assignment of full minerals management authority to the Forest Service for the land it manages; and improved procedures for coordination with states, localities, and the minerals industry.

Research Needs

Increased Forest Service research on the economic, social, and environmental impacts that results from minerals development also will be required so adverse effects can be mitigated and positive benefits enhanced. Research needs include methods of exploring and extracting minerals with minimum impacts on surface resources and maintenance of environmental quality; ways to avoid adverse economic and social impacts and to enhance benefits; and techniques to improve reclamation of mined lands.

Alternative Futures

In order to test the sensitivity of possible RPA Program responses to future conditions, the implications of nine alternative futures for U.S. minerals demand and supply are discussed. It should be emphasized that under any of the alternatives, all minerals will not be affected equally. There will be considerable disparity in the effects on energy, individual metallic minerals, and industrial minerals materials.

The projections of this assessment.—Rising prices for energy and metallic minerals will stimulate exploration for, and development of, domestic minerals resources, which includes lowgrade uneconomic deposits. However, increased prices also will stimulate industry to mine and process minerals more efficiently in order to increase production, reduce waste, and cut costs. Rising prices should also result in more efficient use in manufacturing and consumption. While demand for most minerals will continue to grow, it will be moderated by increased use of advanced composite materials, less use of traditional commodity minerals, greater use of renewable resources, and more recycling.

Improved productivity.—As noted above, rising prices will stimulate increased productivity in mining and processing. Industry will leave less mineral in the ground and recover a greater proportion of the minerals from extracted ores. New technology will improve recovery of minerals and permit the economic recovery of lowgrade deposits.

High exports of minerals.—Rising world prices, regional conflict and political instability of source nations, and improved measures that make domestic minerals cost-competitive with overseas sources could stimulate increased U.S. minerals exports. This would

result in some increased domestic exploration and development. However, for most minerals, exports will represent only a moderate increase in overall demand for domestic resources.

Shortfalls in discovery of domestic minerals.—The United States has developed easily discovered and recovered minerals resources. Those that remain are of lower quality and more difficult to access using conventional technology. The pattern is apparent in the case of oil reserves in the Southwest where expensive technology is required to develop remaining oil. Shortfalls in the discovery of domestic minerals could be met with intensified exploration for hard-to-find deposits, development of low-quality deposits, increased exploration on federal land, and increased investment in new exploration and extraction technology.

Intensified minerals management on public and private lands.—There are national opportunities for intensified minerals exploration and development. As discussed earlier, a number of promising deposits have been identified in the eastern United States. Major opportunities also exist on federal and private land in the West. Whether these opportunities are exploited will depend on the world price of individual minerals and the cost to exploit available domestic reserves. Opportunities to exploit minerals on federal lands will be affected by the designation of additional wilderness areas, the allocation of other lands for specific uses under the new national forest land and resource management plans, and availability of staff to manage minerals.

Changes in land uses that foreclose minerals development.—The amount of available land for minerals development could be reduced by expanding urban areas, the designation of additional wilderness, administrative constraints on minerals development on federal lands, and state and local land use controls. This would result in more pressure on lands open to exploration and development, and possibly a reduction in overall domestic production. Urban expansion can significantly affect the availability of construction minerals on private land, and increase the demand on (and value of) deposits on federal lands close to metropolitan areas. Sand, gravel, and crushed rock will have to be transported longer distances, increasing costs to consumers.

Greater environmental constraints on federal lands.—The production of commodities (timber, minerals, and range forage) are affected by the increase in public interest in noncommodity uses and values of federal lands. Growing noncommodity and environmental concerns can sharply reduce the production of minerals on federal lands. This will require that the Forest Service integrate minerals development with other uses of the national forests; protect the scenic, recreation, water quality, and wildlife values; and maintain the quality of the forest environment.

Reduced consumption of minerals.—A number of developments in combination can reduce the demand for some minerals, particularly gas and oil, uranium, and some of the traditional metallic minerals. Possible developments include a significant rise in world prices of individual minerals, greater use of high-technology composite materials, environmental and safety concerns, the use of renewable resources, and recycling. While demand for some minerals will fall under this scenario, the demand for others (specialty metals such as the platinum group metals, gold and silver, magnesium, and titanium) will rise substantially.

Increased consumption of domestic minerals.—Events could occur that will result in increased demand for some domestic minerals. If, for example, foreign oil producing nations agree to a sharp reduction in production, the resulting rise in prices can stimulate increased production and consumption of domestic oil. Political instability or social unrest can cut off supplies of other important minerals, which increases U.S. reliance on domestic supplies. This will result in increased exploration for, and development of, domestic supplies, and the development of new technology for the recovery and processing of uneconomic reserves of critical minerals.

Policy Questions for Forest Service Programs

The implications of this analysis of the minerals situation in the United States raises a number of public policy questions for the Forest Service. They can be expressed in terms of five questions.

1. To what degree should the Forest Service encourage the exploration for, and development of, minerals, especially metallic minerals, on the National Forest System lands?

Historically, the Forest Service has done little to encourage minerals development on the national forests. The 1872 Mining Act declared the federal domain open to legitimate metallic minerals exploration and development. Forest Service policies and programs are aimed at accommodating mining activity. Generally, the Forest Service has sought to maintain access to national forest lands for minerals development, but made no overt moves to encourage exploitation. Since manufacturers draw from domestic and overseas sources influenced by price, consumers generally benefit by getting the least cost product. However, by encouraging and facilitating minerals development on the national forests, the Forest Service might help reduce price volatility in some market situations.

There are actions the Forest Service can take to encourage and facilitate minerals development on the national forests. The Forest Service can, for example, delineate lands of high minerals potential as special "minerals zones" in national forest land management plans. In these zones, minerals would be considered the primary value, much as recreation is determined the primary value of some areas. It could increase staff capability and develop procedures to expedite reviews of mining plans and the granting of necessary permits and approvals.

There is, however, substantial and growing opposition to mining on the national forests. Opponents contend that mining diminishes the value of large areas for other uses and creates significant environmental

problems. These interests want even tighter controls on mineral development on the national forests.

The emphasis to be given minerals development on the national forests should be addressed in the RPA Program.

2. Should miners be required to pay fair market value for minerals on public lands?

Under terms of the 1872 Mining Law, discoverers of metallic and other valuable minerals are given the right to patent their mining claims on which they have perfected a discovery of such minerals. On the lands where the 1872 Mining Law applies, this can result in the conversion of property from the federal government to the mining claimant. Nominal fees are involved in such transactions. For energy minerals, the federal government receives revenue from annual rentals of the acreage involved and royalties based on production. For mineral materials, sales rates are established by appraisals conducted for the local market area. A policy to charge fair market value for minerals extracted from federal land would have a number of effects. It can discourage some minerals activity on federal land, an effect that would be applauded by opponents of mining on the national forests. On the other hand, such a policy probably would result in increased costs to consumers for some minerals. Moreover, to the extent that charges for minerals taken from federal lands made domestic minerals noncompetitive with overseas sources, both the Nation's gross national product and balance of trade would be negatively affected.

Major and controversial changes in law would be required to permit the Forest Service to charge fair market value for minerals other than mineral materials extracted from the national forests. However, this issue warrants further consideration in the RPA Program.

3. What should the Forest Service do to assure that environmental quality is not impaired as a result to minerals development?

Mining can have a significant effect on the quality of the environment, although technology is available to mitigate most of the adverse impacts. The Forest Service devotes considerable attention to assure that mining is carried out in ways that minimize short-term impacts and results in no irreversible adverse effects to the environment. However, increases in mining activity, and the use of new technologies, require that the Forest Service have the personnel and funds to review minerals development plans and adequately monitor minerals extraction, processing, and' mined-land rehabilitation on the national forests. The RPA Program should address Forest Service programs that protect the environment from the adverse impacts of mining and ways to assure that manpower and funding levels are adequate for the task.

4. To what degree should the Forest Service insulate local communities against the potentially destabilizing social and economic effects of minerals development?

Large-scale minerals development can have both positive and negative effects on communities where mining takes place. Usually, the negative effects occur at the outset of development—large numbers of workers may be attracted to areas not prepared for a major population boom—and again years later as mining activity winds down and ultimately ceases. This deprives a community of an established and substantial industry.

Volatile prices in the minerals industry contribute to short-term disruptions in local economies. Prices that move substantially in a month or two result in swift and major changes in industrial activity—changes felt in local economies, in employment levels, income, consumer spending, and property values. For example, changes in oil prices or production levels from Middle Eastern countries provoke major and rapid changes in exploration and extraction activities in "oil patch" towns in Louisiana, Texas, and Oklahoma. Changes in drilling plans affect leases and purchases in everything from rigs to drilling fluids, catering and transportation services. Employment levels and real estate prices also follow the "boom or bust" cycle. Worker mobility in the oil industry reduces community cohesion; local government service levels rarely adjust fast enough to meet needs. State economies are not immune. Cutbacks in employment and spending increase unemployment compensation costs while reducing income from income and sales taxes. States, that levy severance taxes per barrel and per thousand cubic feet (Louisiana) see those revenues fluctuate as output levels move following price changes.

It is not clear just what alternatives exist for the Forest Service to assist communities in dealing with the negative social and economic effects of mineral activity, but the issue should be addressed in the RPA Program.

5. Should the Forest Service promote more efficient use of minerals in production, processing and manufacturing, and the use of renewable resources, substitutes, and recycling to extend supplies of minerals and reduce pressure to produce on the national forests?

Market forces largely determine the extent to which the mining industry employs more efficient recovery and processing technologies, or the extent to which manufacturers and consumers substitute other materials or recycle. In the case of wood, the Forest Service explicitly promotes more efficient utilization of timber on the national forests, and has research programs intended to extend supplies, so as to slow the rate of increase in the price of timber products. The RPA Program should consider whether the Forest Service could play a constructive role to promote alternatives in the use of minerals.

References

Abelson, P.H. 1987. Energy futures. American Scientist. 75: 584–592.

American Mining Congress. 1987. American Mining Congress declaration of policy. American Mining Congress Journal. October: 11–22.

Argonne National Laboratory. 1988. An assessment of the natural gas resource base of the United States. Washington, DC: U.S. Department of Energy. 126 p.

ASARCO Inc. 1983. The ASARCO Troy Unit, Lincoln County Montana, economic impacts. Troy, MT: ASARCO. 17 p.

Backus, G.A. 1981. Fossil 79: the energy transition policy model. West Lafayette, IN: School of Industrial Engineering, Purdue University. 101 p.

Beeby, D.J. 1988. "Aggregate resources—California's effort under SMARA to ensure their continued availability. Mining Engineering. January: 42–45.

Berck, Peter; Dale, Larry, eds. 1984. Economics and minerals planning. Bulletin 1912. Berkeley, CA: Agricultural Experiment Station, University of California. 110 p.

Blossom, John. 1987. U.S. Department of Interior, Bureau of Mines, Washington, DC. Personal communication, December, 1987.

Cameron, E.N. 1986. At the crossroads: the mineral problems of the United States. New York, NY: John Wiley and Sons, Inc. 320 p.

Dorr, Ann. 1987. Minerals—foundations of society. Alexandria, Va: American Geological Institute. 96 p.

Edelstein, Dan. 1988. U.S. Department of Interior, Bureau of Mines, Washington, DC. Personal communication, February 1988.

Edmunds, J.; Reilly, J. 1986. The IEA/ORAU long-term global energy-CO2 model: personal computer version A484PC. Washington: Oak Ridge Associated Universities. 281 p.

Federal Emergency Management Agency. 1987. Stockpile report to the Congress. Washington, DC: Federal Emergency Management Agency. 70 p.

Fisher, W.L. 1987. Can the U.S. oil and gas resource base support sustained production? Science. 236: 1631–1635. (26 June 1987)

Hargreaves, D.; Fromson, S. 1983. World index of strategic minerals: production, exploitation, and risk. New York, NY: Facts on File, Inc. 300 p.

Honig, R.A.; Olson, Richard J.; Mason, W.T. 1981. Atlas of coal/minerals and important resource problem areas for fish and wildlife in the conterminous United States. Washington, DC: U.S. Department of Interior, Fish and Wildlife Service. 42 p.

Johnson, W.; Paone, J. 1982. Land utilization and reclamation in the mining industry, 1930–80. Information circular 8862. Washington, DC: U.S. Department of Interior, Bureau of Mines. 22 p.

LaMoure, Buster. 1988. Arlington, VA. Interview, March 17, 1988.

Latimer, W.S. 1987. Speech on "Realizing significant cost reductions in the minerals/metals sector: three case histories." Capital Metals Forum Meeting, 1987 November 18: Washington, DC. [Available from W.S. Latimer, ASARCO Inc., 180 Maiden Lake, New York, NY 10038.]

Matthews, O.P.; Haak, Amy; Toffenetti, Kathryn. 1985. Incompatible uses or justifiable compromise? Environment. 27(3): 13–17, 30–35.

McDivitt, James F.; Manners, Gerald. 1974. Minerals and men. Baltimore, MD: Johns Hopkins Press for Resources for the Future. 173 p.

National Academy of Sciences. 1974. Rehabilitation potential of western coal lands. Cambridge, MA: Balinger Publishing Co. 178 p.

National Research Council. 1979. Surface mining of non-coal minerals. Washington, DC: National Academy of Sciences. 339 p.

National Research Council. 1984. Highwall elimination and return to approximate original contour as required in the Surface Mining Control and Reclamation Act. Washington, DC: National Academy Press. 200 p.

PEER Consultants Inc. 1984. Assessment of the effects on soils and waters due to anticipated coal development in the United States: final report. [Available from U.S. Department of Agriculture, Forest Service, Minerals and Geology Management Staff, P.O. Box 2417, Washington, DC 20013.]

Shurr, S.H.; Netschert, B.C. Resources for the Future. 1960. Energy in the American economy 1850–1975. Baltimore, MD: Johns Hopkins Press. 774 p.

Shands, W.E.; Healy, R.G. 1977. The lands noboby wanted: policies for national forests in the eastern United States. Washington, DC: The Conservation Foundation. 282 p.

Sheppard, Carol. 1987. America's first platinum mine dedicated. AMC Journal. September: 6–8.

Sousa, L.J. 1987. Problems and opportunities in metals and materials: an integrated perspective. Washington, DC: U.S. Department of Interior, Bureau of Mines. 111 p.

Stearns, L.B., ed. 1985. Fish and wildlife relationships to mining: symposium proceedings. Wasington, DC: American Fisheries Society, Water Quality Section. 102 p.

U.S. Congress, Office of Technology Assessment. 1979. Management of fuel and nonfuel minerals in federal land: current status and issues. Washington, DC: Government Printing Office. 435 p.

U.S. Department of Agriculture, Forest Service. 1979. An assessment of the forest and range land situation in the United States. Washington, DC: U.S. Department of Agriculture, Forest Service. 352 p.

U.S. Department of Agriculture, Forest Service. 1980. User guide to sociology and economics: mining and reclamation in the West. Gen. Tech. Rep. INT-73. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 53 p.

U.S. Department of Agriculture, Forest Service. 1985. Mining in the national forests. Current Information Report 14. Washington, DC. 18 p.

U.S. Department of Agriculture, Forest Service. 1986a. Working paper on basic assumptions for the 1989 forest service RPA assessment (draft). [Available from Dave Darr, United States Department of Agriculture Forest Service, Forest Resources Inventory and Economics Research Staff, P.O. Box 2417, Washington, DC 20013.]

U.S. Department of Agriculture, Forest Service. 1986b. Forest Service Manual, Title 2800. [Available from U.S. Department of Agriculture, Forest Service, Minerals and Geology Management Staff, P.O. Box 2417, Washington, DC 20013.]

U.S. Department of Agriculture, Forest Service, Minerals and Geology Management Staff, 1988. Interviews. Arlington, VA.

U.S. Department of Commerce, Bureau of the Census. 1984. Census of Mineral Industries 1982. Washington, DC: U.S. Government Printing Office. 44 p. + appendices.

U.S. Department of Commerce, Bureau of the Census. 1986. Statistical Abstract of the United States: 1987. Washington, DC: U.S. Government Printing Office. 960 p.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1987. Deep sea bed mining, vol. 1: final programatic environmental impact statement. Washington, DC. 323 p.

U.S. Department of Energy. 1985. National energy policy plan projections to 2010. Washington, DC: U.S. Government Printing Office. 132 p.

U.S. Department of Energy. 1987a. Annual energy outlook 1986, with projections to 2000. Washington, DC: U.S. Department of Energy, Energy Information Administration. 70 p.

U.S. Department of Energy. 1987b. Annual energy review: 1986. Washington, DC: U.S. Department of Energy, Energy Information Administration. 293 p.

U.S. Department of Energy. 1987c. Energy security: a report to the President of the United States. Washington, DC: U.S. Department of Energy. 240 p. + appendices.

U.S. Department of Energy. 1987d. International energy outlook 1986, with projections to 2000. Washington, DC: U.S. Department of Energy, Energy Information Administration. 73 p.

U.S. Department of Energy. 1987e. Monthly Energy Review, June 1987. 68 p.

U.S. Department of Energy. 1987f. Strategic petroleum reserve: annual/quarterly report. Washington, DC: U.S. Department of Energy, 21 p. + appendixes.

U.S. Department of Interior, Bureau of Land Management. [n.d.] The new western gold rush: an early alert. Memorandum from Bureau of Land Management state director, Nevada to director, Bureau of Land Management, Washington, DC. Available from Nevada State Office, Bureau of Land Management, 850 Harvard Way, P.O. Box 12000, Reno, NV.

U.S. Department of Interior, Bureau of Mines. 1977. 1975 minerals yearbook, vol. 1: metals, minerals and fuels. Washington, DC: U.S. Government Printing Office. 1550 p.

U.S. Department of Interior, Bureau of Mines. 1981. Mineral commodity summaries 1981. Washington, DC: U.S. Government Printing Office. 189 p.

U.S. Department of Interior, Bureau of Mines. 1984. Mineral commodity summaries 1984. Washington, DC: U.S. Government Printing Office. 185 p.

U.S. Department of Interior, Bureau of Mines. 1985. Minerals facts and problems: 1985 edition. Washington, DC: U.S. Government Printing Office. 956 p.

U.S. Department of Interior, Bureau of Mines. 1987a. 1985 minerals yearbook, vol. 2: area reports, domestic. Washington, DC: U.S. Government Printing Office. 635 p.

U.S. Department of Interior, Bureau of Mines. 1986. Mineral Commodity Summaries, 1986, Washington, D.C.: U.S. Government Printing Office. 187 p.

U.S. Department of Interior, Bureau of Mines. 1987b. Mineral commodity summaries 1987. Washington, DC: U.S. Government Printing Office. 189 p.

U.S. Department of Interior, Bureau of Mines. 1988. Mineral commodity summaries 1988. Washington, DC: U.S. Government Printing Office. 190 p.

U.S. Department of Interior, Office of Surface Mining, Reclamation and Enforcement. 1987. Surface coal mining reclamation: 10 years of progress, 1977–1987. Washington, DC: U.S. Department of Interior, Office of Surface Mining Reclamation and Enforcement. 49 p.

U.S. Environmental Protection Agency. 1985. Report to Congress: wastes from the extraction and beneficiation of metallic ores, phosphate rock, asbestos, overburden from uranium mining, and oil shale. Washington, DC: U.S. Government Printing Office. 285 p.

U.S. Environmental Protection Agency. 1987. Unfinished business: a comparative assessment of environmental problems—overview report. Washington, DC: U.S. Environmental Protection Agency. 100 p.

Wenner, Lambert N. 1984. Minerals, people, and dollars: social, economic, and technological aspects of mineral resources development. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region. 139 p.

Wilkinson, C.F.; Anderson, H.M. 1987. Land and resource planning in the national forests. Washington, DC: Island Press. 389 p.

Forest Service Regions and Assessment Regions